This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

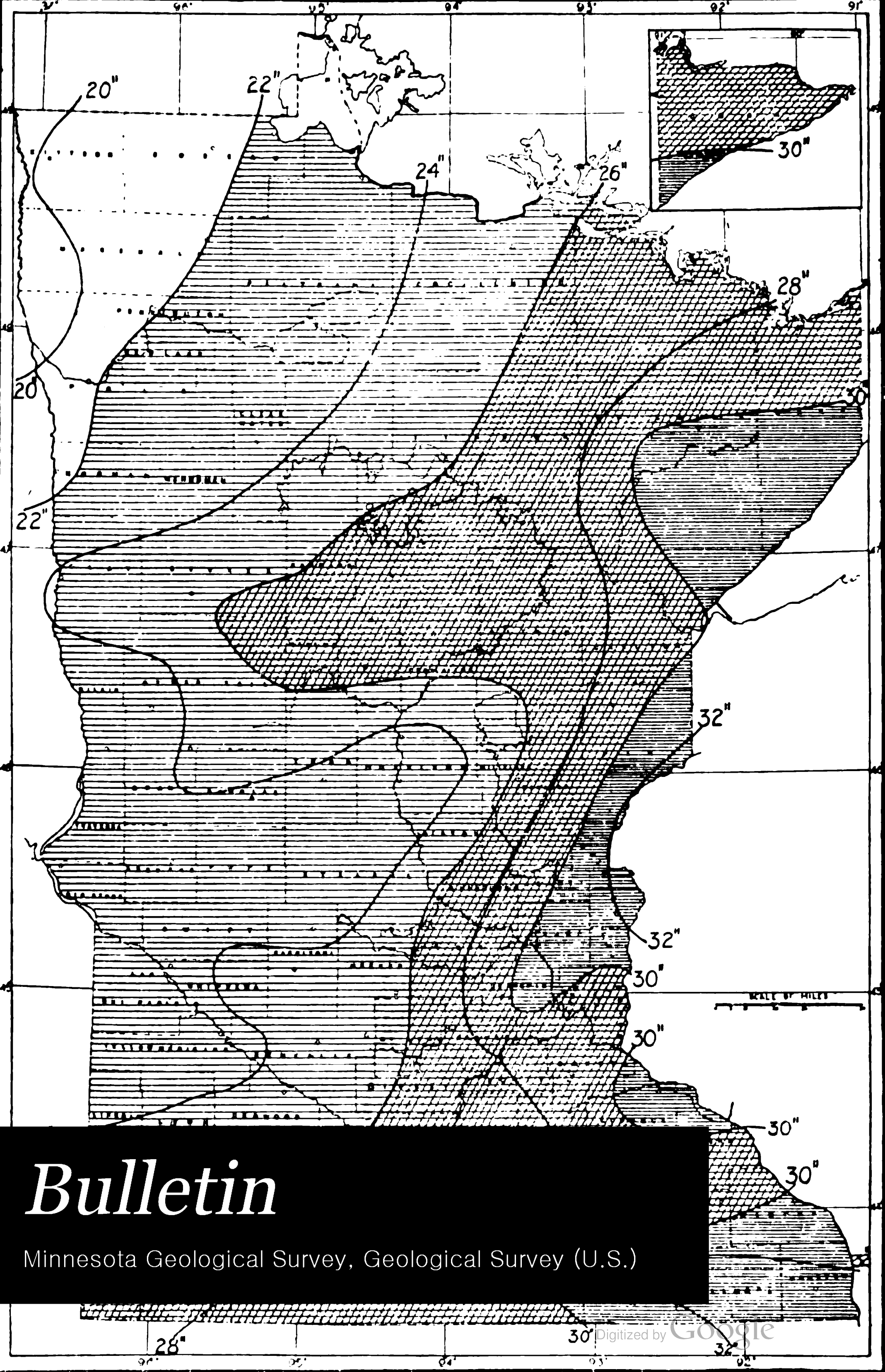
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

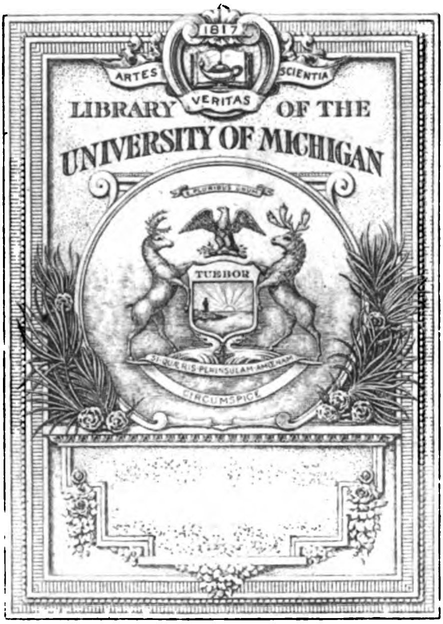
About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`



Bulletin

Minnesota Geological Survey, Geological Survey (U.S.)


1817
ARTES
VERITAS
SCIENTIA
LIBRARY OF THE
UNIVERSITY OF MICHIGAN
E PLURIBUS UNUM
TUEBOR
SI QUÆRIS PENINSULAM AMŒNAM
CIRCUMSPICE

Science Library
QE
127
.A4

UNIV. OF [illegible]
LIBRARY

The University of Minnesota

MINNESOTA GEOLOGICAL SURVEY
WILLIAM H. EMMONS, DIRECTOR

IN COÖPERATION WITH THE UNITED STATES GEOLOGICAL SURVEY

BULLETIN NO. 12

SURFACE FORMATIONS AND AGRICULTURAL CONDITIONS OF NORTHWESTERN MINNESOTA

BY

FRANK LEVERETT

WITH A CHAPTER ON

CLIMATIC CONDITIONS OF MINNESOTA

BY

U. G. PURSSELL

Minneapolis
The University of Minnesota
1915

Science

CONTENTS

Introduction 1–3

Field work and acknowledgments 5–6

Chapter I. Topography of Minnesota 7–9
  General features of the drift 7
  Altitude 7
  Relief 8
  Drainage 8
  Lakes 9

Chapter II. Climatic conditions, by U. G. Purssell 10–29
  Introduction 10
  General climatic conditions 11
    Temperature 11
    Frosts 18
    Precipitation 23
    Snowfall 26
    Winds 26
    Relative humidity 26
    Number of rainy days 27
    Sunshine 27
    Tables showing temperature, precipitation, winds, etc 28–29

Chapter III. Surface geology 30–37
  Rock areas 30
  The earthy mantle 30
    General statement 30
      Residuary material 31
      Wind deposits 31
        Loess 31
        Wind-blown sand 31
    Glacial deposits 33
    Stream deposits 34
    Lake deposits 34
  The glacial features 35
  Glacial lake features 36

Chapter IV. General soil conditions 38–41

Chapter V. Agricultural conditions and land classification in the northwest quarter of Minnesota 42–75

General statement 42
Description of counties.................................... 42
- Kittson County 43
- Roseau County 45
- Marshall County 47
- Pennington County 49
  - Report by W. G. Smith.................................... 50
- Red Lake County.................................... 51
- Polk County 53
- Clearwater County 55
- Beltrami County 57
- Western Koochiching County.................................... 60
- Northwestern Itasca County.................................... 61
- Parts of Cass and Crow Wing counties.................................... 62
- Hubbard County 64
- Wadena County 65
- Northern Ottertail County.................................... 66
- Becker County 67
- Mahnomen County 70
- Norman County 71
- Clay County 72
- Northern Wilkin County.................................... 74

LIST OF ILLUSTRATIONS

Plate I. Map of the surface formations of Minnesota (Sheet I) in pocket.
II. A. Plowing for seeding on a clay plain in bed of Lake Agassiz.
B. Harvesting crop on a clay plain in bed of Lake Agassiz 10
III. A. Flax field on Red River clay plain
B. Potato field on Red River clay plain
C. Corn field on Red River clay plain (July 15th, 1914) 26
IV. A. River scene at Roseau, Minnesota
B. Wheat field on clay plain on bed of Lake Agassiz
C. Homestead on clay plain on bed of Lake Agassiz 34
V. A. Till plain in Mahnomen County
B. Wheat field on till plain in Mahnomen County. 42
VI. A. Homestead on clay moraine in Ottertail County
B. Oats (and corn in background) on clay moraine in Ottertail County........................... 50
VII. Views on gravel outwash plains near Wadena...... 58
VIII. A. Draining a muskeg swamp in Roseau County
B. Drained swamp in Pennington County with forest on lake, washed till in background....... 66

TEXT FIGURES

Fig. 1. Map showing average annual temperatures of Minnesota (degrees Fahrenheit) 12
2. Map showing average temperatures of Minnesota for January (degrees Fahrenheit)...................... 14
3. Map showing average temperatures of Minnesota for July (degrees Fahrenheit)......................... 15
4. Map showing highest known temperatures in Minnesota (degrees Fahrenheit) 16
5. Map showing lowest known temperatures in Minnesota (degrees Fahrenheit) 17
6. Map showing average date of last killing frost in spring in Minnesota 19

7. Map showing average date of first killing frost in autumn in Minnesota 20
8. Map showing number of days of the average crop-growing season in Minnesota 21
9. Map showing the average annual precipitation for Minnesota 22
10. Diagram showing comparative monthly distribution of precipitation in Minnesota 24
11. Mean monthly rainfall and mean monthly temperature at several stations in Minnesota 24
12. Diagram showing rainfall and temperatures (degrees Fahrenheit) at St. Paul, Minnesota, from 1837-1913 25
13. Map showing distribution of glacial drift, loess, and glacial lakes in Minnesota, by Frank Leverett 32
14. Map of Minnesota showing distribution of forest and prairie after map by Warren Upham and by Frederic K. Butters 39

INTRODUCTION

By W. H. Emmons

The natural economic assets of an area, such as its soils, clays, building stones, iron ores, etc., all bear a direct relation to the geological features of that area, and a rational discussion of such assets must give due importance to the geological history and environment of the area which contains them. The last, and, therefore, from the standpoint of the soils and surface features of the country the most important, great geological event that has affected this area is the invasion of sheets of ice that moved southward from the Canadian highlands carrying with them rocky material which they had gathered in the north. When the ice melted it left large quantities of rock and soil and in the area here described this material nearly everywhere now forms the surface.

The last great ice sheet that covered this area melted very slowly and the southern part was melted long before the northern part. The ice that still remained in the north formed a great dam which held back the drainage of the Red River Basin and formed a large lake which is called the glacial Lake Agassiz. This lake overflowed southward through the Minnesota River and into the Mississippi. These conditions endured through a long period and this lake was partly filled with material that washed into it and its bottom was washed and smoothed over by waves and shore currents. Later, when at the north the ice dam melted, the lake was drained to the north, and its bottom now forms one of the largest and richest agricultural regions of the world. This lake was drained very gradually, however, its level remaining stationary through considerable periods so that gravel beaches were formed here and there along its shores. These gravel beaches supply material for roads and they furnish also attractive building sites for farmhouses and barns.

After the ice had melted, large swamps and marshes occupied poorly drained portions of the region and many of them remain to the present day. The drainage and reclamation of these lands is one of the most important problems of this region.

The great productivity of Minnesota soils is due, not only to their recent origin by reason of which nearly all of them still contain the soluble mineral foods for plants, but also to a very favorable climate. The low temperatures which frequently prevail during certain periods in winter make for healthful conditions for animal life and they also benefit plant life. The rainfall, though not excessively great, is sufficient and, since most of it occurs during the growing period, drouths are rare and crop failures almost unknown except in the more sandy soils, which are, however, adapted to quick-growing crops like potatoes. As shown herein, the length of the crop-growing season, that is, the time between late spring frosts and early autumn frosts, is between 100 and 170 days for all except the extreme northeast corner of the State, and in the southern half is nearly everywhere above 130 days, a period that is ample for growing the highly productive crops of Indian corn. The long days, high proportion of sunshine, and the moderate humidity are all favorable to plant growth.

This bulletin is a preliminary paper which treats the soils of only the northwest quarter of Minnesota. It will be followed by a report on the entire State, the field work for which will soon be completed. The work has been done in accordance with the agreement for coöperation between the United States Geological Survey and the Minnesota Geological Survey, entered into March, 1912. By this agreement the services of Professor Frank Leverett were secured for surveying the surface formations and soils. Mr. Leverett has been engaged for some twenty years in studying the surface geology of the Great Lakes region and because of his large experience in the greater area he is particularly well prepared to undertake the studies in Minnesota. He has spent, moreover, considerable time in the State studying its physiography in connection with the preparation of a monograph for the United States Geological Survey. Since the reorganization of the State Survey, the salary of Mr. Leverett has been met by the United States Geological Survey, while the greater part of his expenses have been paid by the State Survey. The State Survey has provided also for this work the services and expenses of Professor F. W. Sardeson, who has assisted in this work for the past three seasons. For brief periods, also, the State has supplied the services of Arthur H. Elftman, P. R. McMiller, and G. R. McDole. We wish to acknowledge the generous assistance of the Division of Soils of the Department of Agriculture of the University of Minnesota and of the United States Bureau of Soils, both of which have contributed unpublished data. The valuable contributions to the knowledge of the surface formations of Minnesota by the Minnesota Geological and Natural History Survey, under the direction of Professor N. H. Winchell, particularly those of Mr. Warren Upham of that Survey, have aided greatly in the preparation of this report. The section on climatic conditions in Minnesota has been generously contributed without any cost to the Survey by Mr. U. G. Purssell, Director of the Minnesota Section of the United States Weather Bureau. In the preparation of the maps and other data showing dates of killing frosts, lengths of growing season, rainfall, etc., Professor C. J. Posey has rendered efficient service.

The cost of preparation of this report has been met by the Minnesota Geological Survey and the United States Geological Survey. This bulletin is printed by the Minnesota Geological Survey. Arrangements will be made so that land and colonization companies can secure these reports at actual cost of printing, and it is expected that this arrangement will secure a wide distribution. The maps are not intended to be used as a basis for the purchase of land; they do not give an accurate description of each forty-acre tract or each section, but they show the general classification of the land, its climate, and its surroundings.

SURFACE FORMATIONS AND AGRICULTURAL CONDITIONS IN NORTHWESTERN MINNESOTA

By Frank Leverett

FIELD WORK AND ACKNOWLEDGMENTS

This report treats particularly the northwest quarter of Minnesota, but a brief general description of the surface features and deposits of the entire State is given because the larger area makes a more natural unit for purposes of description. For this reason, also, Mr. Purssell has discussed the climate of the entire State. In this report no attempt is made to measure the crop-growing capacity of any class of soil, or the adaptation of certain soils to particular crops. These matters fall naturally to the Department of Farm Management. It seems pertinent, however, to note that soils which are classed as light may under intelligent management be made to yield returns which compare favorably with the yield from heavier soils. The sandy areas shown on the map which accompanies this report thus afford an inviting field for experimentation. The drainage and utilization of the great swamps constitute another large field for intelligent operation.

The productiveness of a soil usually has some relation to its origin and to underground conditions. It therefore means more to say that a given soil is a glacial lake clay or a lake sand than merely to call it a clayey soil or a sandy soil. If formed of the very productive wind-deposited material called loess, there is an advantage in making this appear in the name rather than merely to term it a silt loam. So also the pebbly clay loams and pebbly sandy loam of the glacial deposits may have one degree of productiveness in a level till plain and quite another in a hilly moraine. It is for this reason that pains have been taken in the legend of the map to set forth the geologic as well as the soil names. Another reason for this mapping and description is that the method of the work is genetic rather than analytic. It deals with the origin of the formations in larger divisions rather than with the physical conditions section by section and area by area. It is not sufficiently detailed to justify the purchase or sale of the land from an examination of the map alone. It gives, however, an accurate general classification of the land and its surroundings.

The field work of this report on Minnesota was begun in 1906. The writer has devoted to this work a considerable part of each field season to 1914, except 1908. Field assistance has been rendered four seasons by Frederick W. Sardeson as geologist, and one season each by Rollin T. Chamberlin and Earl R. Preston as field assistants. Arthur H. Elftman furnished valuable information and accompanied the writer for a brief period in 1913 into the wild portion of the State with which he was especially familiar from work on an earlier State Survey. Field conferences have been held also with members of the United States Bureau of Soils and of the State Department of Agriculture. The map and report on Pennington County and part of Polk County here presented is based largely upon the work of the Bureau of Soils. In the preparation of this report much aid has been derived from the monograph on the glacial Lake Agassiz by Warren Upham and from the reports of counties in the Final Reports of the Geological and Natural History Survey of Minnesota. Free use has been made also of the reports and maps of the State Drainage Commission.

CHAPTER I

TOPOGRAPHY OF MINNESOTA

GENERAL FEATURES OF THE DRIFT

Minnesota presents more variety in surface features than most of the North Central states, though a great part of it has a level or gently undulating surface. The flattest portion falls largely in the northwest quarter of the State and was once the bed of a great lake known as glacial Lake Agassiz, held in on the north by a sheet of ice or great glacier. The roughest portion is in the northeast quarter which is traversed by volcanic formations and adjacent iron-bearing ranges. In the southeast part along the borders of the Mississippi River there are tributary valleys from 300 to 600 feet deep cut in horizontal beds of sandstone and limestone of that district. There is an elevated area in the southwest part rising in places to over 1,900 feet above sea level, but it has a relatively smooth surface because the inequalities of the rock surface are concealed under a great deposit of drift. The interior of the State has features due entirely to the ice, or great glacier, and its melting waters. It comprises a complex system of undulating to hilly moraines, sandy outwash plains, and clayey till plains, whose extent and distribution bear definite relation to the melting of glaciers that overspread the region.

At and beneath the border of the ice, systems of interlocking ridges and knolls with inclosed basins and lakes, were formed at certain definite lines where the edge of the ice held its position for a relatively long time. These systems are the moraines. The ice border, after long holding its position at one of these moraines, would recede somewhat rapidly to another position and there halt long enough to build up another moraine and so on step by step until the ice had disappeared from the State. On the outer border of a moraine there is often a plain of sandy gravel spread out as an outwash by waters escaping from the ice. On the inner border there is usually a clayey plain known as till plain which was ice-covered during the development of the moraine.

Large areas were covered by lakes as the ice was melting away, and thus much of the drift has been lake-washed and rendered somewhat smoother than the unmodified glacial deposits. Many of these lakes have disappeared because their shallow basins have been filled up.

ALTITUDE

In Minnesota altitudes range from 602 feet, the level of Lake Superior, up to 2,230 feet on high knolls in western Cook County. The altitude is only 620 feet where the Mississippi River leaves the southeast corner of the State, and is 750 feet along Red River in the northwest corner. The headwaters of the Mississippi and the Leaf Hills farther south reach 1,750 feet. The average altitude of the State is not far from 1,200 feet and a large part of it stands between 1,000 and 1,500 feet. A narrow area below 1,000 feet covers the Red River Valley and extends from it into the Minnesota Valley and expands to considerable width in the eastern part of the State. There is another narrow strip below 1,000 feet on the border of Lake Superior. The chief areas above 1,500 feet are found in the rocky ranges of the northeast part, in the high tract from the head of the Mississippi to the Leaf Hills in the western part, and in the plateau southwestward from Coteau des Prairies in the southwest part. Only a few square miles in the northeast part rise above 2,000 feet.

RELIEF

The most conspicuous relief is found in the "Sawtooth Range" and other prominent ridges that closely border Lake Superior and which rise abruptly from 500 to 900 feet above the lake. The rock ranges lying back from the shore, though more elevated than those fronting on the lake, seldom rise more than from 200 to 300 feet above the swamps and lakes among them. In fact several of the lakes of Cook County are above 1,900 feet or within 300 feet of the level of the highest points in the State. The most prominent part of the Mesabi Iron Range in St. Louis County rises from 400 to 450 feet above bordering plains. The Coteau des Prairies rises about 700 feet above the plain northeast of its border, but in Minnesota the rise is usually spread over a space of from 12 to 15 miles or more in width, so that the elevation can scarcely be appreciated by one crossing over it. There is a rather rapid rise of from 300 to 500 feet to the sharp range of hills in Ottertail and Becker counties from the Red River Valley. This rise is of especial interest since it seems to have some influence on the rainfall, the precipitation being greater in these hills where air currents are forced upward and cooled than in the bordering lower lands to the north, west, and south.

DRAINAGE

The drainage of Minnesota is widely divergent, part of it leading to the Gulf of Mexico, part to the Gulf of St. Lawrence, and part to Hudson Bay. The Gulf of Mexico receives about 57 per cent, the St. Lawrence less than 9 per cent, and Hudson Bay fully 34 per cent of the drainage. There was a time, however, after the glacial ice had melted from Minnesota but was still occupying the northeast part of the

Superior Basin and neighboring parts of Ontario and Manitoba, when all the drainage was southward to the Gulf of Mexico. The western Superior Basin then overflowed into the St. Croix River, while the Red River Drainage Basin, largely covered by Lake Agassiz, drained southward through Lakes Traverse and Bigstone into the Minnesota Valley.

The drainage to the south, or Gulf of Mexico, has generally a gentle descent, and waterfalls are rather rare, though the Mississippi has notable falls at Minneapolis and there are one or more falls or rapids on several of the tributaries. The drainage to Lake Superior is generally rapid and nearly every stream has several cascades. There is, however, a wide area of the upper St. Louis Basin in which that stream and its tributaries have relatively gentle descent for many miles. The Hudson Bay Drainage has a few rapids and waterfalls in the headwater part of Rainy River and its tributaries, but Red River and its main Minnesota affluent Red Lake River have no falls since no outcrops of solid rock occur along them. There is, however, very rapid descent for a few miles along Red Lake River and its tributary Clearwater River in Red Lake County. Red River is subject to great freshets because its lower course often remains frozen after the southern or headwater part has broken up. Thus ice jams are formed which divert the waters from the channel over the bordering plain.

LAKES

Throughout much of Minnesota, except the northwest, southwest, and southeast corners, small lakes are a common feature. They usually occupy basins among the moraine ridges and knolls and on the outwash plains, but occur to some extent also on the till plains and among rock knobs. The combined area of the lakes within the State is estimated to be about 5,650 square miles, or nearly 7 per cent of the entire area. The largest lake is Red Lake, a very shallow body of water with an area of 440 square miles. Other large lakes are Mille Lacs, also very shallow, Leech, Winnibigoshish, and Minnetonka. Minnetonka and the southern part of Leech Lake extend into a network of deep depressions among morainic ridges, but the other lakes are largely in plains that are slightly below the neighboring districts, partly morainic and partly plain.

CHAPTER II

CLIMATIC CONDITIONS OF MINNESOTA

By U. G. Purssell

Director of the Minnesota Section of the United States Weather Bureau

INTRODUCTION

The agriculture of any region is controlled by its climate. In some parts of the world temperature is the main factor in determining the limits of growth of certain kinds of crops; in others it is rainfall, and in still others it is the amount of sunshine. All of these factors are important in influencing the crop yield even in districts where the general climatic conditions are satisfactory for the growth of plants. In Minnesota these elements are so favorable that a majority of the crops common to the temperate zone may be successfully grown, and a failure of all the important crops is very rare even over a small portion of the State.

Rainfall is an important factor for most crops in the State, because the proper amount of water in the soil at the critical period of development of the plant is necessary to produce a large crop. The length of the growing season also is important and probably no other factor in the study of climate from the standpoint of the agriculturist should be given more consideration. This is the key to an actual knowledge as to the possibilities of success or failure in the production of crops since in parts of the State crops are menaced by frost at some period of their growth, whereas sunshine and moisture seldom vary in Minnesota beyond safe limits.

The State extends from the northern boundary of Iowa, latitude 43° 30′, some 400 miles northward to the farthest point north in the United States, which is 22.85 miles beyond the 49th parallel in the projection to the northwest point of the Lake of the Woods. The greatest width east and west is 367 miles.

The factors which determine the climate of any area are the relative distribution of land and water, the topography of the land surface, and the situation of the area in question with relation to the general movement of the cyclones and anti-cyclones.

The position of Minnesota at the center of North America gives it a climate that is largely continental. In continental climates the temperature extremes are greater and the humidity and rainfall generally less than at places near large bodies of water, such as border on the Atlantic, Pacific, and Gulf coasts of the United States. The effect of

A. PLOWING FOR SEEDING ON A CLAY PLAIN IN BED OF LAKE AGASSIZ

B. HARVESTING CROP ON A CLAY PLAIN IN BED OF LAKE AGASSIZ

winds from great bodies of water is to equalize temperatures of lands near by and to lengthen materially the crop-growing season. This is particularly true of the country in the vicinity of Lake Superior, where the influence of that great inland sea in modifying the cold anti-cyclones gives to that section a more equable climate than would otherwise obtain in that portion of the State. The summer temperatures are likewise modified and people from long distances inland in steadily increasing numbers are establishing summer homes about the lake, to which they are attracted during the hot summer months. There are more than 7,000 small lakes scattered throughout the State and these have a material local influence in modifying the heat of summer and give comfort to thousands of residents on their shores.

Monthly and annual reports of temperature, rainfall, snowfall, etc., have been published for a large number of regular and coöperative stations in Minnesota since 1895. Recently three special section reports have been issued by the United States Weather Bureau giving monthly and annual precipitation totals for all points in the State with a record of ten years or over, together with average temperatures and other data. In these reports the more important facts from all portions of the State are tabulated and the comparative climatic conditions of the different sections graphically shown.

GENERAL CLIMATIC CONDITIONS

Minnesota is in the path of a large proportion of the low-pressure areas which move across the United States from west to east. These areas move at an average speed of 600 miles in twenty-four hours and are preceded by southerly winds and higher temperature and followed by northerly winds and lower temperature. They are usually accompanied by cloudy weather and precipitation; each storm causing an average of from one to two rainy days as it crosses the State.

As there is an average of almost two of these storms each week with fair weather periods between, it follows that the changes in weather conditions are rather rapid. One or two days of stormy weather preceded by fair weather and followed by clearing and lower temperatures to be repeated in turn, make up the usual routine for the week. However, Minnesota is so far from the coast that damaging ocean storms lose much of their severity before reaching its borders.

The northwestern cold waves pass across the State and send their health-giving winds into all parts, and yet they are frequently not so severe as they are in some of the plains states in the same latitude or even farther south.

Temperature.—The average annual temperature of Minnesota for the

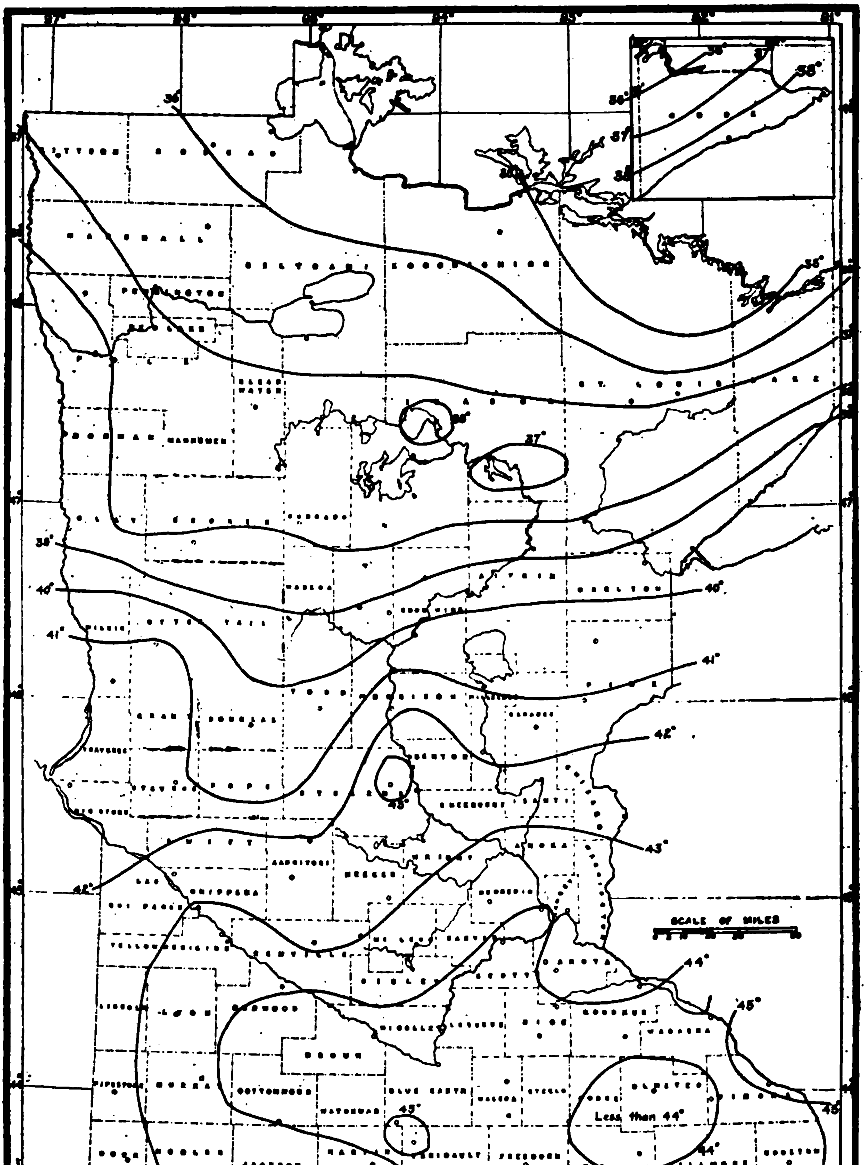


FIGURE 1. MAP SHOWING MEAN ANNUAL TEMPERATURES OF MINNESOTA (DEGREES FAHRENHEIT)

period 1895 to 1913 inclusive, is 41.7°, as shown in Table I and graphically by Figure 1. The highest annual mean temperature, 43.9°, occurred in 1900, and the lowest, 39.9°, in 1912. The departure of the average temperature of any year from the normal may readily be determined by comparing the yearly average with the mean at the foot of the column.

Table I. Monthly and Annual Mean Temperature for Minnesota (Degrees Fahrenheit)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1895..........	......	......	......	49.9	56.9	64.6	67.8	67.4	61.5	41.4	27.8	18.3	......
1896..........	12.3	17.9	21.4	44.5	60.9	66.5	69.9	67.9	54.3	42.4	18.0	20.3	41.6
1897..........	7.2	15.3	20.7	43.7	55.2	62.5	71.6	64.2	65.3	50.0	26.6	12.3	41.2
1898..........	18.3	16.4	30.3	43.5	55.6	67.0	69.8	66.9	60.6	42.9	26.6	11.9	42.2
1899..........	9.9	4.5	14.7	44.0	55.1	65.4	70.2	69.1	56.4	49.0	39.6	17.9	41.2
1900..........	18.4	5.2	23.4	49.5	59.9	66.8	68.8	74.3	58.2	55.1	25.4	18.6	43.9
1901..........	13.2	10.0	27.3	46.7	58.2	65.5	74.7	69.8	57.3	49.2	28.8	13.0	42.8
1902..........	15.9	15.5	34.0	42.6	57.0	61.3	69.7	65.2	55.2	47.1	33.3	12.6	42.6
1903..........	11.3	10.6	29.6	43.3	55.7	62.3	67.2	63.6	55.5	46.1	27.3	9.8	40.3
1904..........	4.5	2.3	24.8	38.8	55.4	63.2	66.0	64.9	57.4	47.4	36.7	16.7	40.1
1905..........	5.6	8.9	33.7	42.0	52.6	63.0	67.3	68.9	61.9	43.5	33.1	20.6	41.5
1906..........	17.0	13.8	20.6	47.9	53.7	63.7	68.3	68.7	63.3	45.7	30.7	15.9	42.0
1907..........	3.8	14.8	28.7	34.7	45.5	63.3	68.2	66.1	55.9	45.4	31.7	21.3	40.1
1908..........	16.4	17.9	26.4	45.2	53.9	62.5	69.4	65.5	64.2	47.0	33.8	17.5	43.4
1909..........	10.5	13.7	26.1	35.8	53.2	65.0	69.2	70.9	58.7	44.7	33.8	10.0	41.0
1910..........	11.8	7.5	41.7	48.0	51.6	67.8	70.6	65.8	58.4	50.8	25.3	14.7	42.8
1911..........	5.4	16.6	32.7	42.7	59.8	69.7	68.2	64.0	56.7	43.4	20.2	19.4	41.6
1912..........	−6.7	10.6	19.8	45.5	55.9	62.5	68.5	63.9	57.2	47.5	33.9	20.0	39.9
1913..........	7.2	8.6	20.4	46.4	52.7	67.4	67.3	69.2	58.6	42.7	36.9	26.1	42.0
1914..........	16.9	2.8	26.6	41.2	57.6	64.6	72.4	66.1	60.0	52.6	33.0	......	......
Mean....	10.5	11.2	26.5	43.8	55.3	64.7	69.3	67.1	58.8	46.5	30.1	16.7	41.7

The coldest month is January, which has a mean temperature of 10.5°, although the average for February is only 0.7° higher. In a great many instances February has averaged colder than the preceding January. This condition occurred in the seven successive years from 1898 to 1904 inclusive. Average January temperatures are plotted on Figure 2.

July is the warmest month, with an average temperature of 69.1°, although in a few years the mean temperature for June or for August is higher than for July of the same year. Average July temperatures are plotted on Figure 3.

The highest summer mean, 70.0°, occurred in 1900 and 1901. The coldest summer was that of 1903, with an average of 64.4°.

The warmest crop-growing season (April to September inclusive) of the eighteen years under discussion was in 1900, when the average was 62.9°, and the coldest was in 1907, with an average of 55.6°.

The warmest winter (December to February inclusive) was in 1907-8, when the mean temperature was 18.5°. The coldest was in 1903-4, with a mean temperature of 5.5°. Table II shows also the warmest and coldest spring and autumn.

In Figures 4 and 5 are shown the highest and lowest temperatures ever recorded in the various counties where records have been kept.

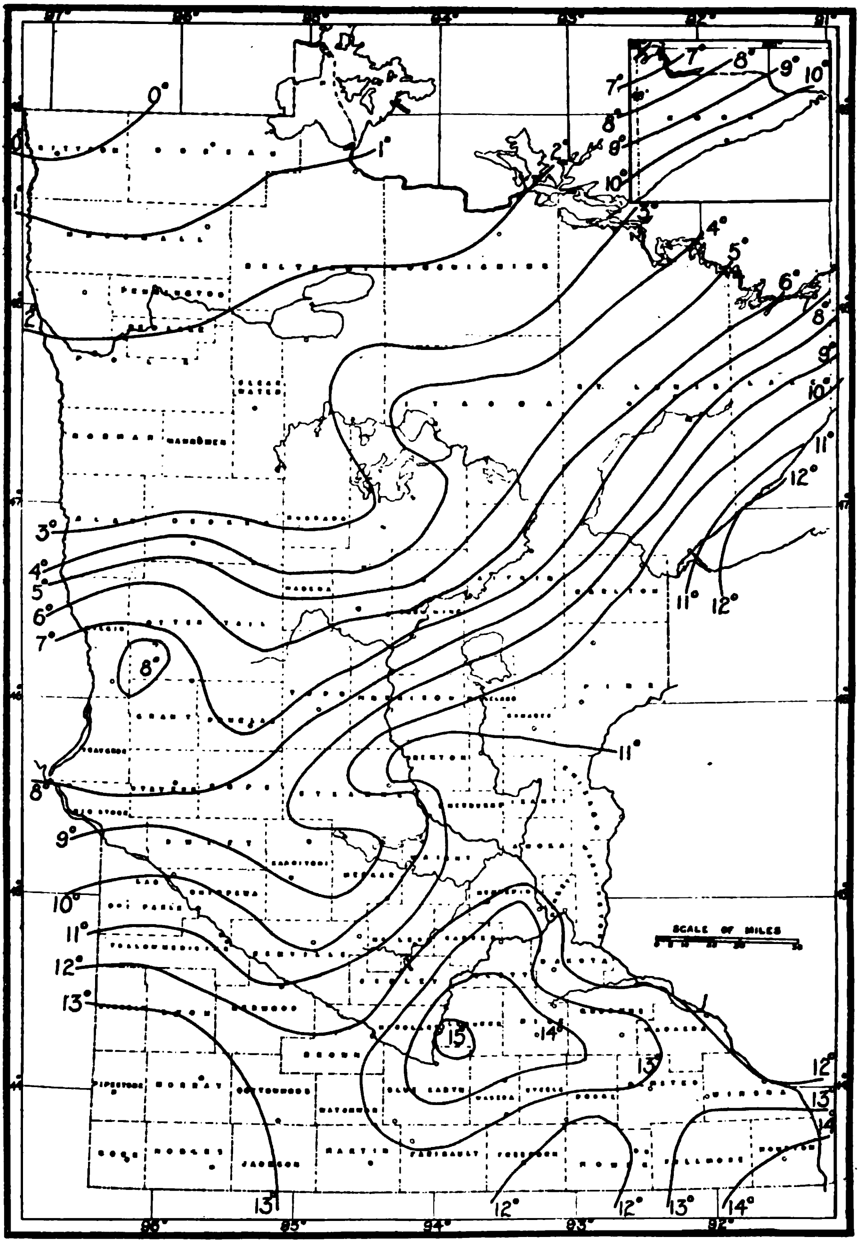


FIGURE 2. MAP SHOWING MEAN TEMPERATURES OF MINNESOTA FOR JANUARY (DEGREES FAHRENHEIT)

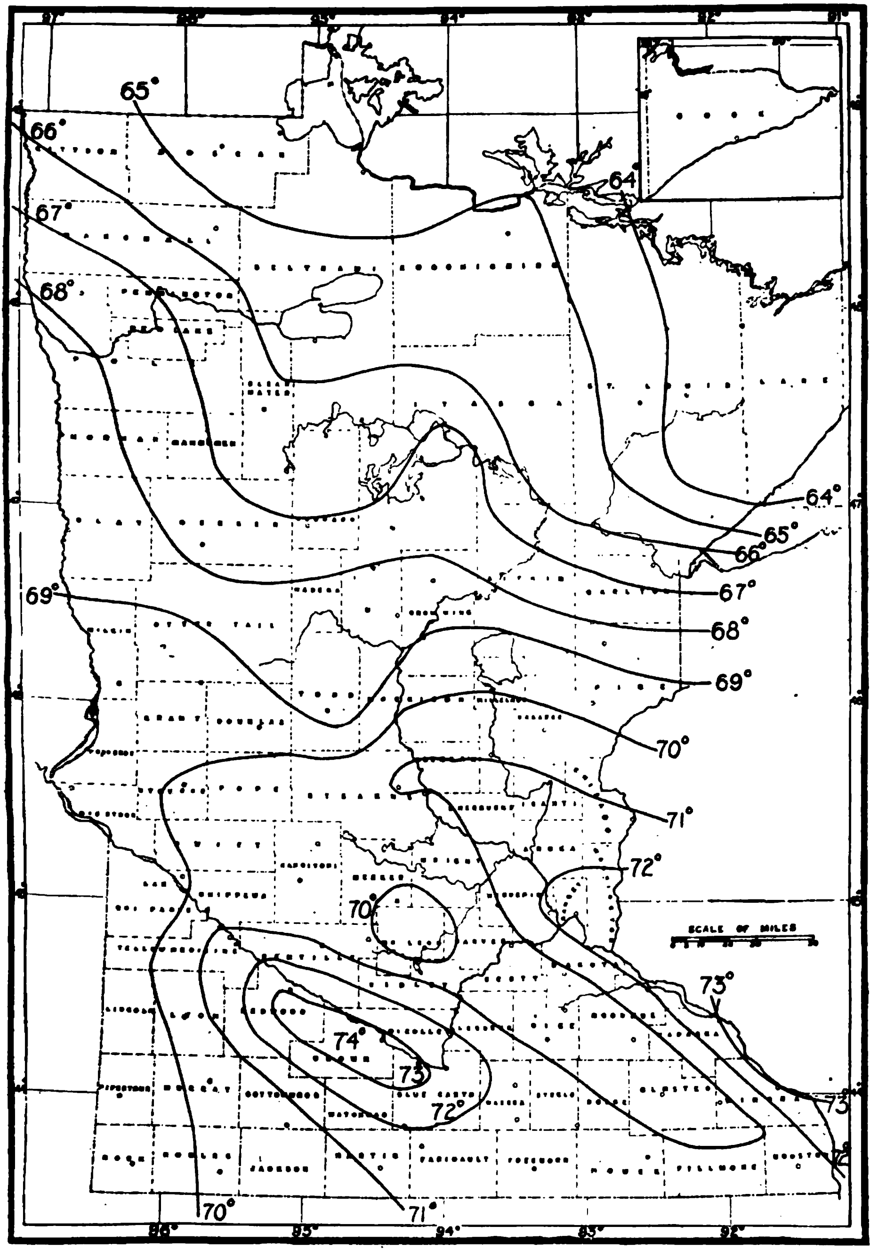


FIGURE 3. MAP SHOWING MEAN TEMPERATURES OF MINNESOTA FOR JULY (DEGREES FAHRENHEIT)

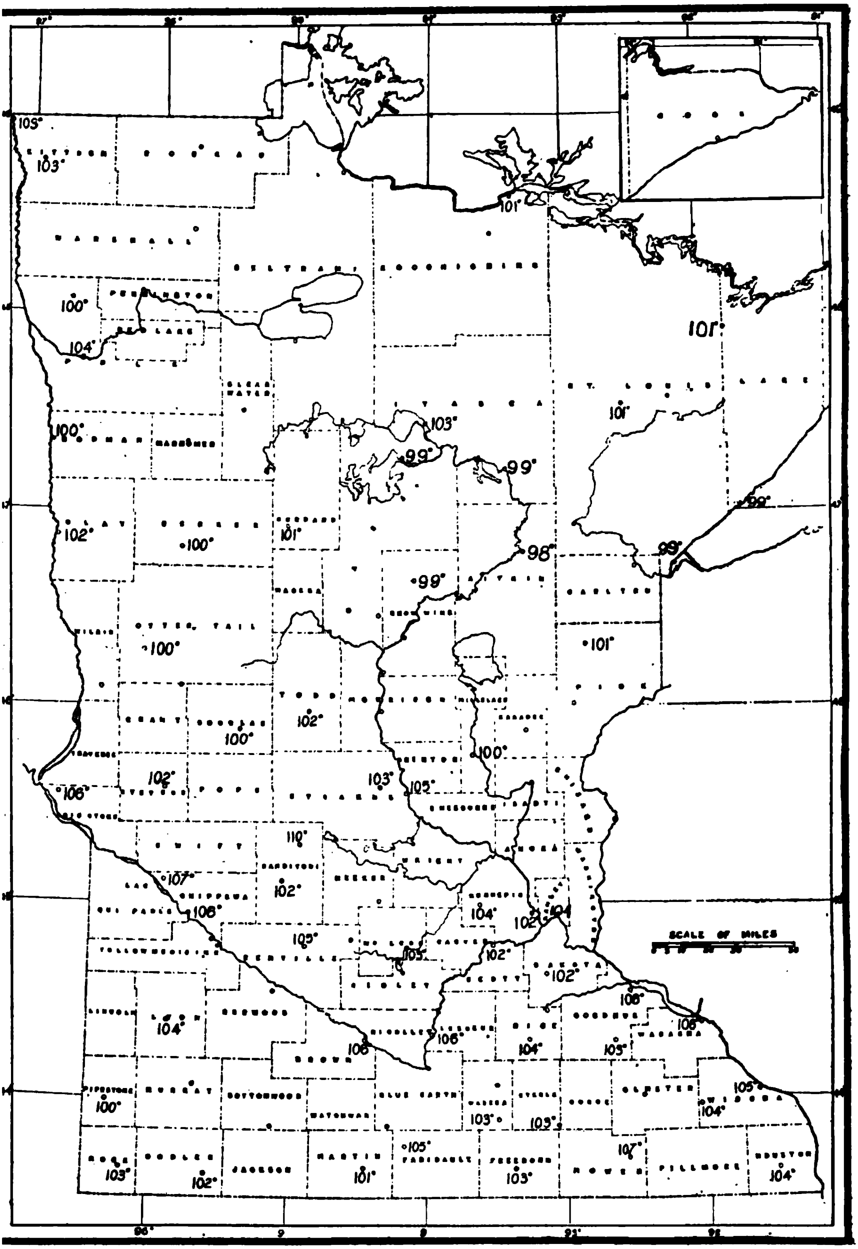


FIGURE 4. MAP SHOWING HIGHEST KNOWN TEMPERATURES IN MINNESOTA (DEGREES FAHRENHEIT)

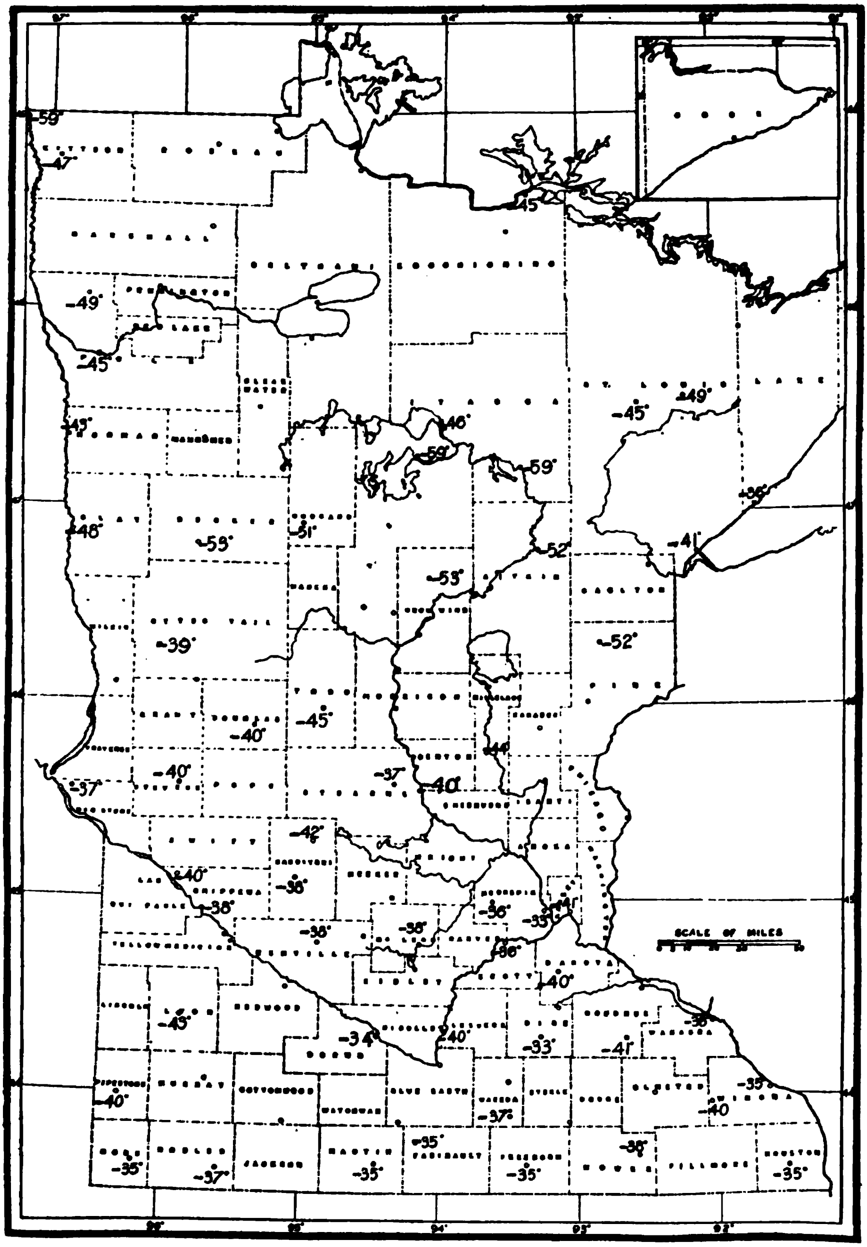


FIGURE 5. MAP SHOWING LOWEST KNOWN TEMPERATURES IN MINNESOTA (DEGREES FAHRENHEIT)

From these figures it can readily be seen that the extreme range of temperature is from 107° at Grand Meadow and Milan, to — 59° at Leech Lake Dam and Pokegama Falls. Temperatures above 100° have been recorded in all counties except those about the headwaters of the Mississippi River, and in the country immediately bordering on Lake Superior. Temperatures of — 40° have occurred in nearly all northern and central counties and in a few southern counties, but these great extremes do not occur frequently.

Table II. Seasonal Temperatures for Minnesota (Degrees Fahrenheit)

Year	Winter mean	Spring mean	Summer mean	Fall mean	April to Sept. inclusive (crop-growing season)
1895					61.4
1896	16.2	42.3	68.1	38.2	60.7
1897	14.3	39.9	66.1	47.3	60.4
1898	15.7	43.1	67.9	43.4	60.6
1899	8.8	37.9	68.2	48.3	60.0
1900	13.8	44.3	70.0	46.2	62.9
1901	13.9	44.1	70.0	45.1	62.0
1902	14.8	44.5	65.4	45.2	58.5
1903	11.5	42.9	64.4	43.0	57.9
1904	5.5	40.0	64.7	47.2	57.6
1905	10.4	42.8	66.4	46.2	59.3
1906	17.1	40.7	66.9	46.6	60.9
1907	11.5	36.3	65.9	44.3	55.6
1908	18.5	41.8	65.8	48.3	60.1
1909	13.9	38.4	68.4	45.7	58.8
1910	9.8	47.1	68.1	44.8	60.4
1911	12.2	45.1	67.3	40.1	60.2
1912	7.8	40.4	65.0	46.2	58.9
1913	11.9	39.8	68.0	46.1	60.3
1914	15.3	41.8	67.7	48.5	60.3
Mean	12.8	41.7	67.0	45.3	59.8

Frosts.—Although frosts have occurred in some portions of the State every month of the year, damaging temperatures are not to be expected during June, July, and August, and they are comparatively rare in the last half of May and the first half of September. Records of ten or more years are available from a large number of places in the State, of which charts have been constructed showing the average date of the last killing frost in spring and the first one in autumn. Using these dates as boundaries, we can mark the average beginning and ending of crop growth and determine the average length of the growing season. All of this information is graphically shown in Figures 6, 7, and 8. By reference to Figure 8 the influence of Lake Superior in lengthening the crop-growing season in its vicinity may be seen; while in the same latitude in the highlands of Hubbard, Becker, eastern Mahnomen, and Clearwater counties the season is twenty to thirty days shorter. The longest season, 160 days, obtains along the Mississippi River from Hennepin County to the southeastern corner of the State, and the shortest, 100 days or less, is in the region of the Mesabi and Vermilion Iron Ranges.

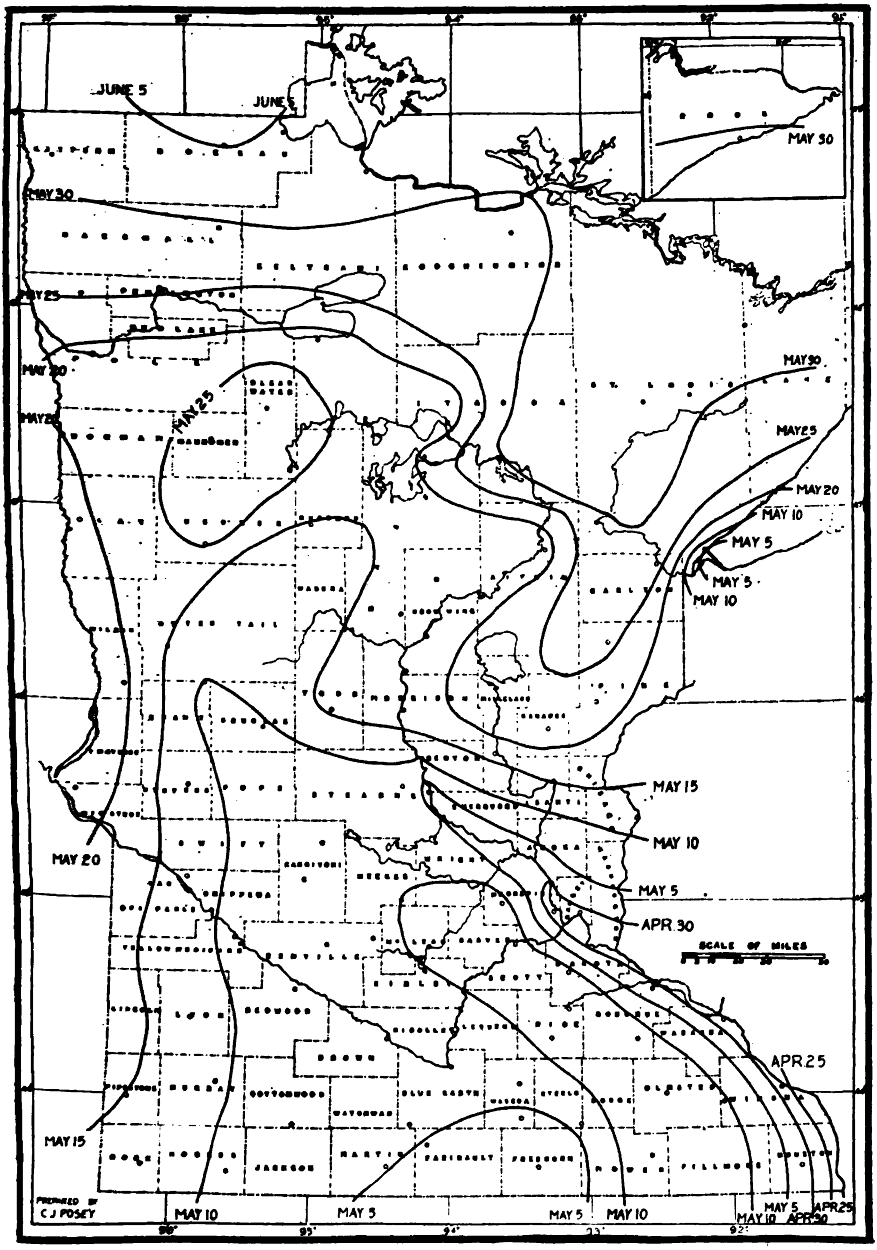


FIGURE 6. MAP SHOWING AVERAGE DATE OF THE LAST KILLING FROST IN SPRING IN MINNESOTA

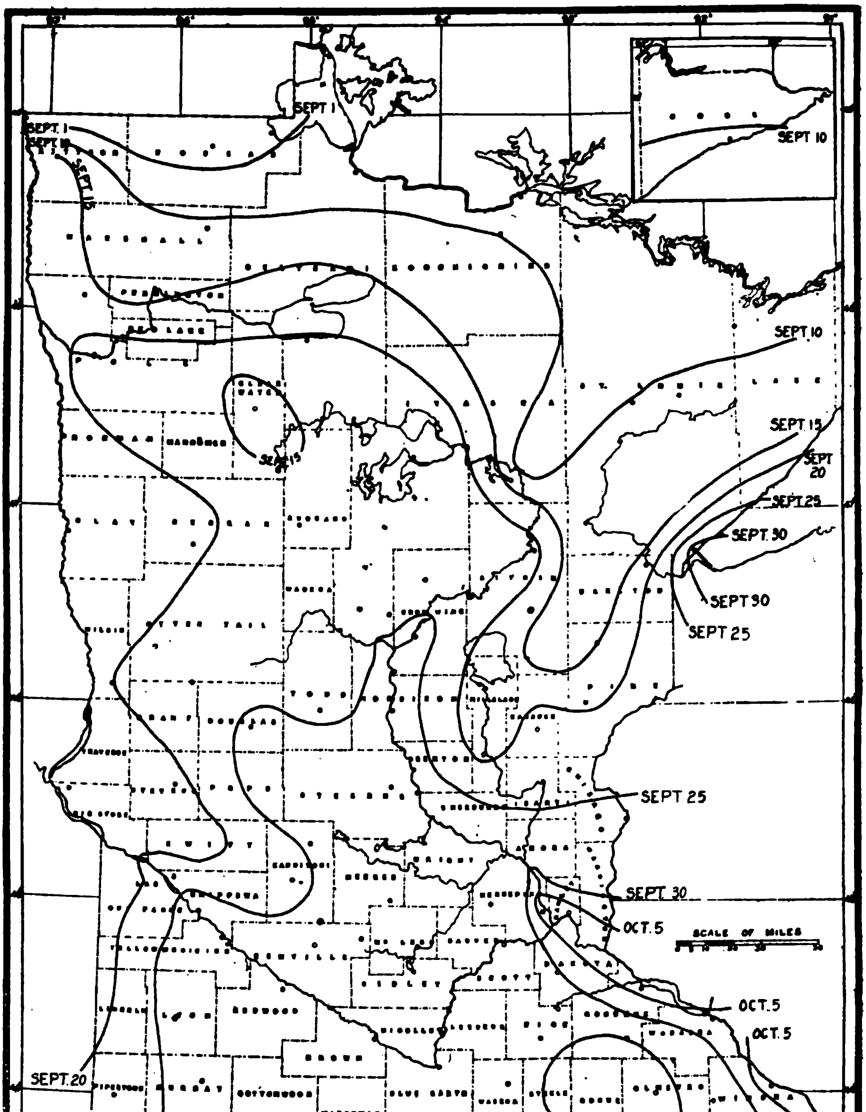


FIGURE 7. MAP SHOWING AVERAGE DATE OF FIRST KILLING FROST IN AUTUMN IN MINNESOTA

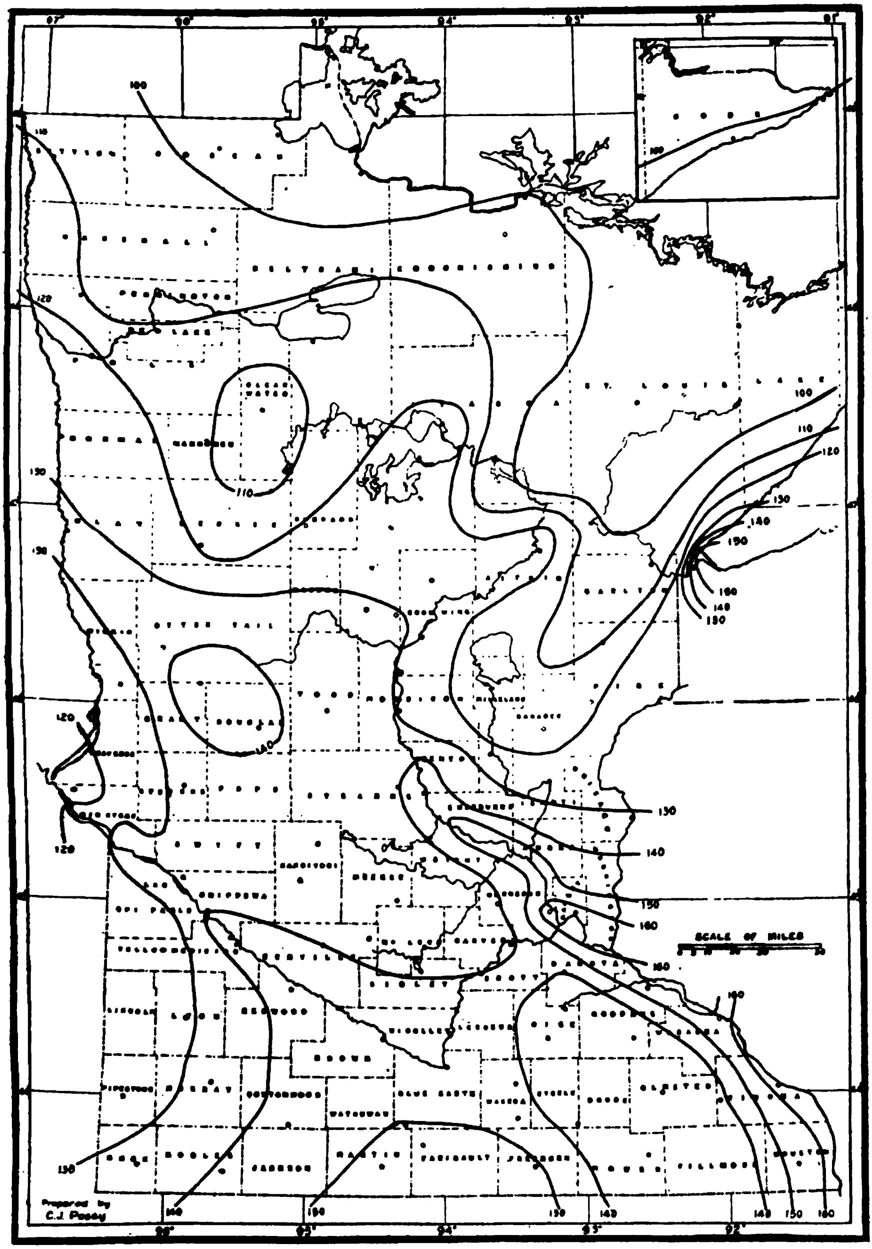


FIGURE 8. MAP SHOWING NUMBER OF DAYS OF THE AVERAGE CROP-GROWING SEASON IN MINNESOTA

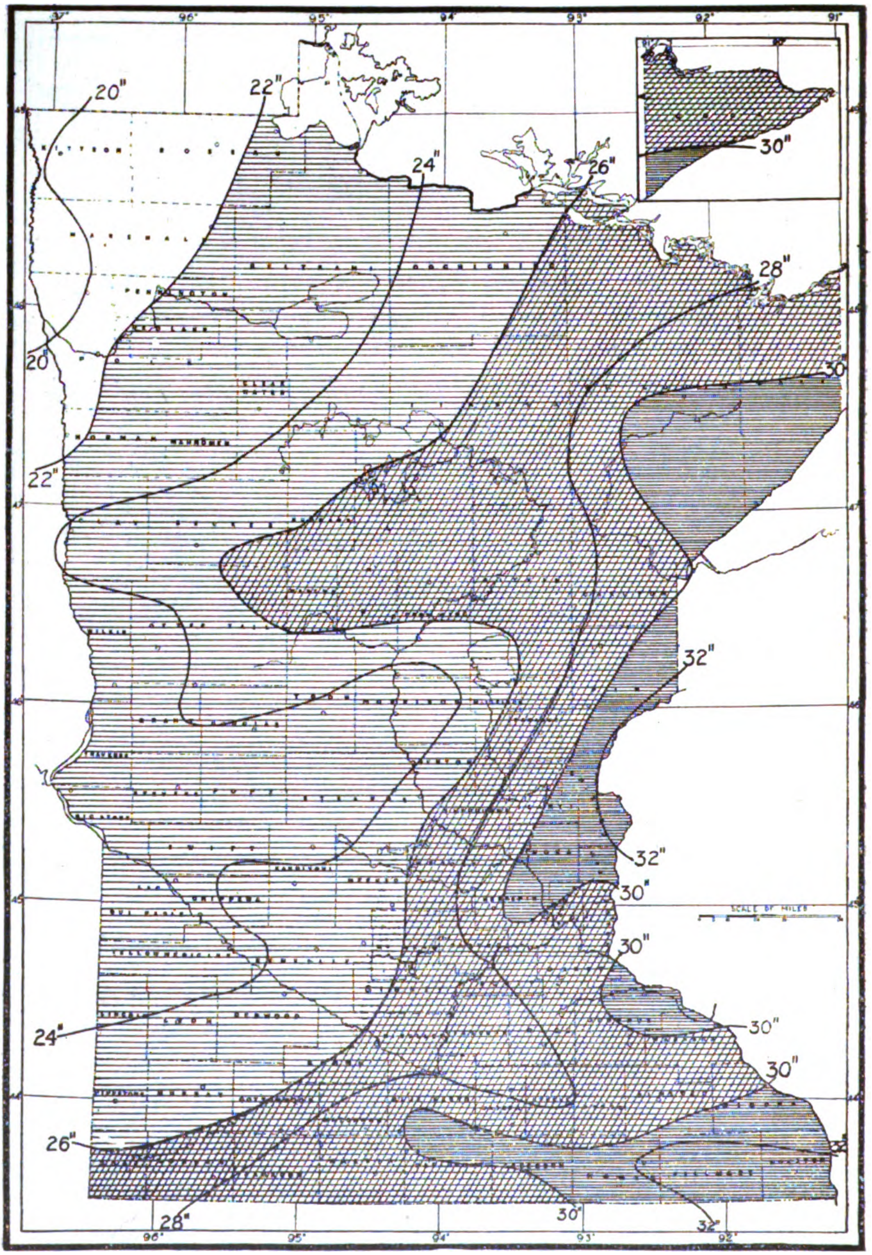


FIGURE 9. MAP SHOWING THE AVERAGE ANNUAL PRECIPITATION FOR MINNESOTA

Table III. Average Monthly and Annual Precipitation for Minnesota (in Inches)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Total April to Sept. incl.
1895....	......	......	......	1.68	3.30	4.37	3.25	2.27	3.93	0.25	1.22	0.28	....	18.80
1896....	0.76	0.39	1.97	5.91	5.02	4.07	1.88	2.28	2.49	2.95	2.69	0.61	32.04	21.65
1897....	1.77	1.21	2.07	1.55	1.38	5.40	6.62	2.54	1.89	1.55	0.53	0.38	27.23	19.38
1898....	0.16	1.02	1.21	1.64	3.26	3.93	2.94	3.22	1.52	3.83	1.02	0.18	24.21	16.51
1899....	0.60	0.78	1.58	1.49	4.46	6.36	2.84	5.35	1.47	3.22	0.63	0.95	30.14	21.97
1900....	0.48	0.56	1.30	1.47	0.90	1.71	5.48	6.44	6.55	3.85	0.62	0.51	29.79	22.55
1901....	0.38	0.40	1.68	1.73	1.41	5.81	3.33	2.21	4.34	1.86	0.78	0.57	24.26	18.83
1902....	0.44	0.67	0.92	1.67	5.10	3.32	4.76	4.35	2.23	1.93	1.57	1.79	29.46	21.43
1903....	0.45	0.59	1.75	2.82	5.37	1.96	5.11	4.65	5.63	3.13	0.35	0.84	32.85	25.54
1904....	0.39	0.62	1.51	1.72	2.43	4.26	3.96	2.77	3.14	3.50	0.14	0.82	29.65	18.28
1905....	0.65	0.55	1.21	1.46	5.54	6.41	4.12	4.36	3.45	2.53	2.64	0.15	33.10	25.34
1906....	1.15	0.27	1.20	1.72	5.58	4.55	2.93	4.66	3.73	2.28	1.82	0.91	31.66	23.17
1907....	1.17	0.58	0.94	1.01	2.14	4.31	3.57	4.11	3.48	1.31	0.57	0.57	24.03	18.62
1908....	0.31	1.11	1.47	2.55	6.31	6.35	3.21	2.07	2.41	1.91	1.18	0.79	29.49	22.90
1909....	1.32	1.31	0.54	1.89	3.36	3.53	3.84	4.54	3.16	1.56	2.68	1.54	29.27	20.32
1910....	0.83	0.45	0.27	1.54	1.58	1.39	1.94	2.35	2.45	0.97	0.52	0.44	14.73	11.25
1911....	0.81	0.88	0.63	1.88	3.48	3.79	3.61	4.27	3.35	3.93	1.12	1.35	29.10	20.38
1912....	0.40	0.21	0.45	2.04	4.13	1.66	4.30	3.97	3.03	0.97	0.36	0.93	22.45	19.13
1913....	0.33	0.44	1.27	1.87	3.53	3.08	5.56	2.79	3.33	2.58	0.66	0.05	25.49	20.16
1914....	0.81	0.44	1.12	2.41	2.89	8.34	2.48	3.97	3.08	2.00	0.38	......	....	23.77
Mean..	0.70	0.66	1.22	2.00	3.56	4.18	3.79	3.66	3.23	2.31	1.07	0.71	27.72	20.33

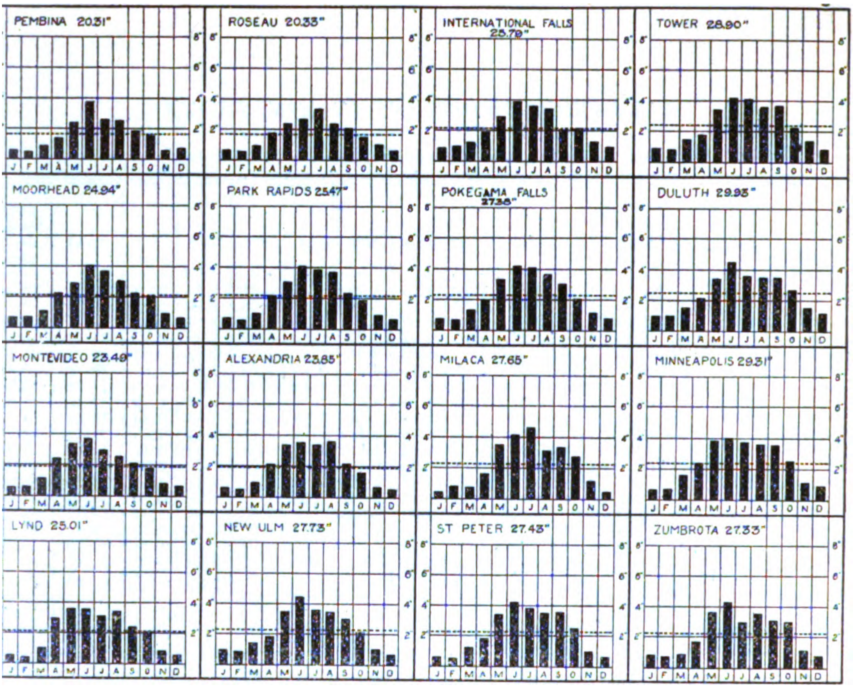
Precipitation.—The annual average precipitation of the State as a whole for a period of eighteen years, 1896 to 1913 inclusive, is 27.72 inches, and for the crop season, April to September inclusive, for nineteen years, 1895 to 1913, is 20.16 inches. The monthly, seasonal, and annual averages for this period are shown in Table III. The year with the greatest annual rainfall was 1905, when the total was 33.10 inches. The driest year was 1910 with 14.73 inches. In that year the rainfall during the crop-growing season was 11.25 inches.

Table IV. Average Monthly and Annual Precipitation by Drainage Districts

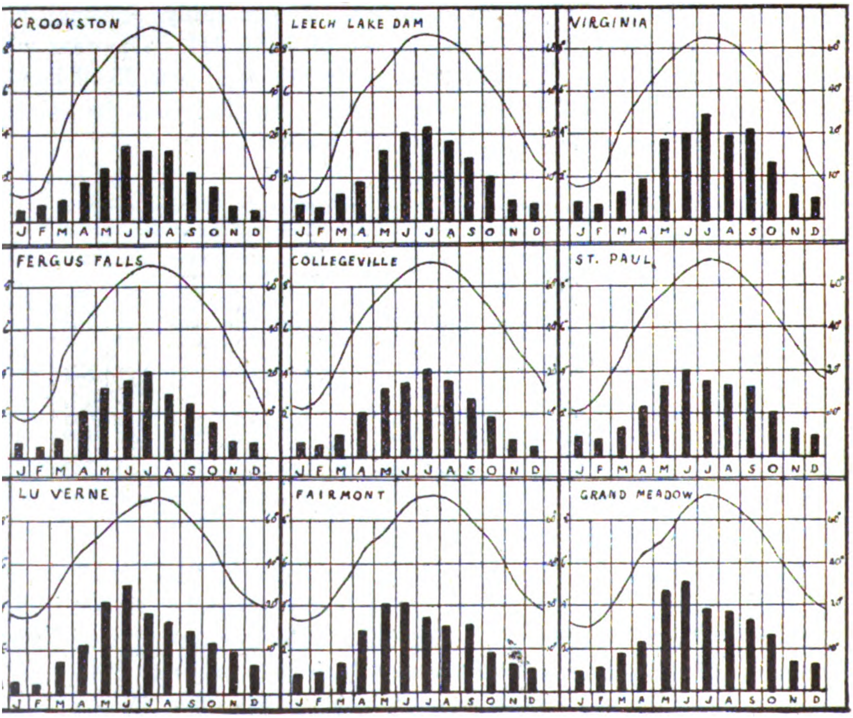
Watersheds	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Lake Superior...	0.88	0.88	1.41	2.05	3.50	4.19	4.21	3.73	4.18	2.80	1.45	1.13	30.40
Rainy River.....	0.94	0.94	1.42	1.96	3.10	4.04	3.76	3.32	2.98	2.08	1.46	0.98	26.98
Red River......	0.55	0.56	0.98	1.84	2.85	3.83	3.34	3.12	2.32	1.55	0.72	0.56	22.22
Mississippi (above St. Croix).....	0.73	0.70	1.23	2.16	3.42	4.13	3.61	3.57	3.00	2.29	1.05	0.73	26.63
St. Croix and Mississippi (below St. Croix).....	0.92	0.95	1.49	2.37	4.01	4.46	3.72	3.69	3.72	2.73	1.36	1.13	30.57
Minnesota River.	0.79	0.73	1.19	2.30	3.52	4.18	3.34	3.44	2.63	2.11	1.02	0.79	26.04
Big Sioux and Des Moines Rivers.	0.50	0.54	1.13	2.09	4.00	4.39	3.49	3.58	2.79	2.07	0.94	0.63	26.15
State.......	0.76	0.75	1.25	2,18	3.53	4.19	3.55	3.50	3.02	2.24	1.09	0.84	26.90

June is the wettest month with an average rainfall of 4.18 inches, and July is next with 3.79 inches. The lowest monthly rainfall is that of February with an average of 0.66 inch. The greatest rainfall in one month for the State as a whole was 8.34 inches in June, 1914. The lowest rainfall for any month was .05 inch in December, 1913.

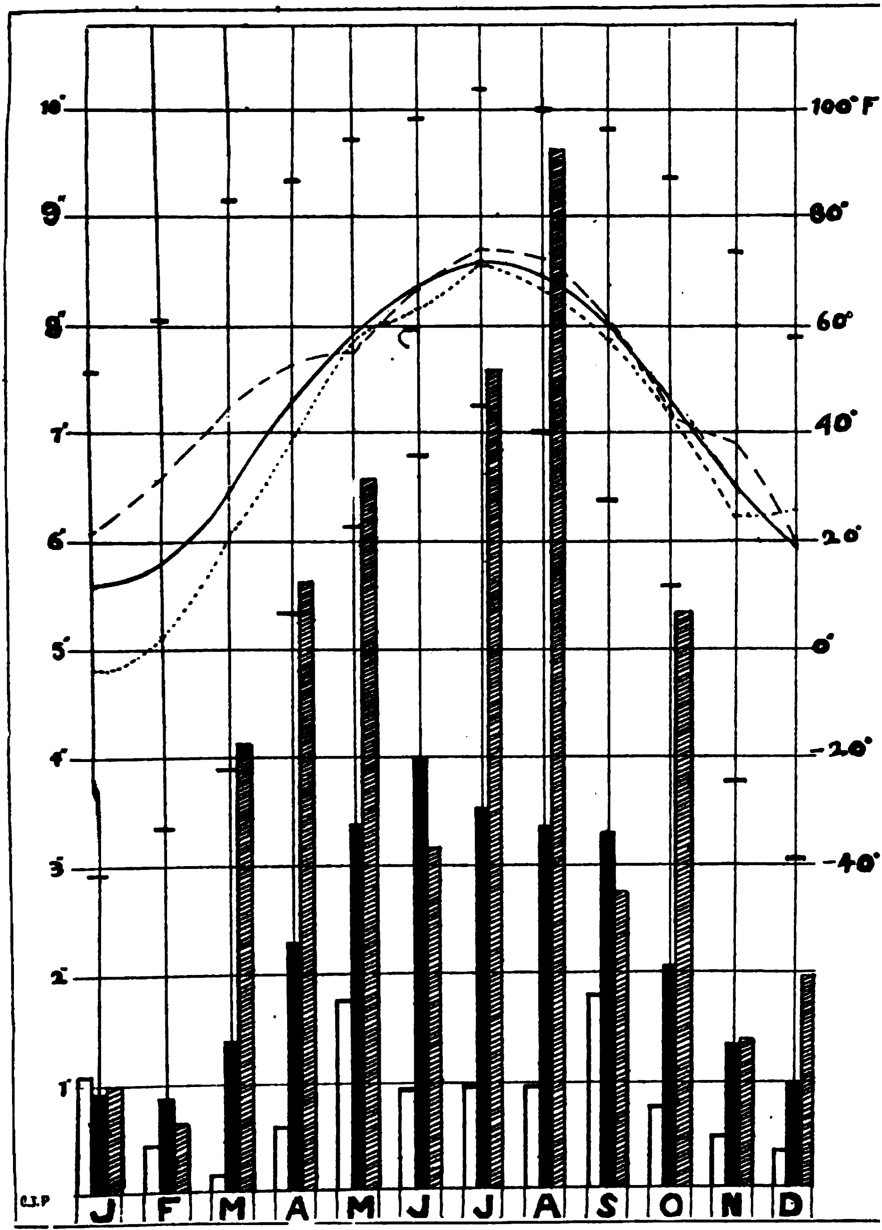
The geographic distribution of annual and monthly precipitation is



GURE 10. DIAGRAM SHOWING COMPARATIVE MONTHLY DISTRIBUTION OF PRECIPITATION IN MINNESOTA. LETTERS INDICATE MONTHS, BLACK COLUMNS INDICATE INCHES OF RAINFALL IN EACH MONTH AT STATION NAMED



IGURE 11. MEAN MONTHLY RAINFALL AND MEAN MONTHLY TEMPERATURE AT SEVERAL STATIONS IN MINNESOTA. MONTHS ARE INDICATED BY THEIR FIRST LETTERS. THE GREATEST RAINFALL IS IN THE GROWING SEASON



■ =mean monthly rainfall, 1837-1913.
▨ =monthly rainfall of year of greatest rainfall recorded, 1849
□ =monthly rainfall of year of least rainfall recorded, 1910.
Solid curve=mean monthly temperature, 1871-1913.
Dotted curve=mean monthly temperature for year of lowest annual temperature recorded, 1875.
Dashed curve=mean monthly temperature for year of highest annual temperature recorded, 1878.
Horizontal dashes show absolute maximum and minimum temperatures recorded.

FIGURE 12. DIAGRAM SHOWING RAINFALL AND TEMPERATURES (DEGREES FAHRENHEIT) AT ST. PAUL, MINNESOTA FROM 1837-1913. MONTHS ARE INDICATED BY THEIR FIRST LETTERS

graphically shown in Figures 9 to 11, and for the stations having ten or more years of record in Table V. Table IV shows the monthly and annual distribution in the various watersheds. From these illustrations it may be seen that the precipitation is about one-fourth to one-third greater along the eastern boundary of the State than along the western boundary.

Table V. Average Annual Precipitation in Minnesota by Stations

Station	County	Length of record	Average annual precip.	Station	County	Length of record	Average annual precip.
		Yrs.	Inches			Yrs.	Inches
Albert Lea	Freeborn	21	29.90	Montevideo	Chippewa	22	23.50
Alexandria	Douglas	25	23.74	Moorhead	Clay	31	24.92
Angus	Polk	10	19.00	Morris	Stevens	27	23.23
Ashby	Grant	14	24.47	New London	Kandiyohi	18	23.62
Beardsley	Bigstone	16	23.79	New Richland	Waseca	10	29.91
Bird Island	Renville	22	24.23	New Ulm	Brown	32	27.74
Blooming Prairie	Steele	13	27.45	Northfield	Rice	12	29.92
Caledonia	Houston	19	33.70	Osceola, Wis	Polk	21	32.13
Collegeville	Stearns	19	22.76	Park Rapids	Hubbard	22	25.71
Crookston	Polk	22	22.41	Pembina, N. D	Pembina	14	19.79
Detroit	Becker	16	25.96	Pine River Dam	Crow Wing	25	27.52
Duluth	St. Louis	41	29.93	Pipestone	Pipestone	12	24.18
Fairmont (near)	Martin	25	28.20	Pokegama Falls	Itasca	25	27.62
Faribault	Rice	14	28.00	Red Wing	Goodhue	16	31.71
Farmington	Dakota	24	29.29	Redwood Falls	Redwood	13	24.65
Fergus Falls	Ottertail	24	23.24	Reeds Landing	Wabasha	16	29.31
Flandreau, S. D	Moody	22	24.57	St. Charles	Winona	21	30.68
Fort Ripley	Crow Wing	43	25.25	St. Cloud	Sherburne	19	27.68
Glencoe	McLeod	15	26.64	St. Paul	Ramsey	41	28.68
Grand Meadow	Mower	24	32.59	St. Peter	Nicollet	18	27.89
Grantsburg, Wis	Burnett	21	33.06	Sandy Lake Dam	Aitkin	19	26.47
Hallock	Kittson	13	21.37	Shakopee	Scott	15	28.85
Halstad (Ada)	Norman	16	21.27	Tonka	Hennepin	13	30.54
International Falls	Koochiching	10	25.75	Tower (Ely)	St. Louis	10	28.17
La Crosse, Wis	La Crosse	40	31.17	Two Harbors	Lake	18	30.56
Leech Lake Dam	Cass	24	27.00	University, N. D	Grand Forks	20	20.47
Long Prairie	Todd	20	25.17	Virginia (Mt. Iron)	St. Louis	18	30.74
Luverne	Rock	15	27.60	Wabasha	Wabasha	17	30.54
Lynd	Lyon	19	25.43	Wahpeton, N. D	Richland	20	23.67
Mankato	Blue Earth	14	27.50	Willmar	Kandiyohi	10	25.54
Mapleplain	Hennepin	17	31.11	Willow River	Pine	10	29.98
Milaca	Mille Lacs	13	27.27	Winnebago	Faribault	14	30.58
Milan	Chippewa	18	24.49	Winnibigoshish	Itasca	25	25.66
Milbank, S. D	Grant	21	22.69	Winona	Winona	16	29.63
Minneapolis	Hennepin	21	29.31	Worthington	Nobles	17	28.24

Figure 11 makes an interesting comparison of monthly and annual values of both temperature and rainfall at certain selected representative stations.

Snowfall.—The snowfall averages from 24 to 54 inches. It is lightest in the southwest portion of the State and heaviest on the Mesabi Iron Range. The monthly and annual averages are shown in Table VI, arranged according to sections and drainage districts.

Winds.—The prevailing winds are from the northwest over most of the State. The monthly and annual prevailing directions are shown for a large group of stations in Table VII. The average hourly wind velocity is shown for six regular Weather Bureau stations and three special stations in Table VIII.

Relative humidity.—The average annual humidity for the State is

A. FLAX FIELD ON RED RIVER CLAY PLAIN

B. POTATO FIELD ON RED RIVER CLAY PLAIN

C. CORN FIELD ON RED RIVER CLAY PLAIN

Table VI. Average Snowfall

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
	Yrs.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Lake of the Woods Group—														
Tower	9	9.0	8.6	10.9	4.2	0.6	0	0	0	0.2	0.4	8.4	8.2	50.5
Red River Valley Group—														
St. Vincent-Pembina	14	8.4	5.1	6.9	5.2	0.7	0	0	0	0.1	0.7	5.7	6.4	39.2
Crookston	14	6.3	6.7	8.8	3.2	0.2	0	0	0	T.	0.4	4.5	5.7	35.8
Moorhead	17	7.6	6.7	8.9	4.9	0.3	0	0	0	0.1	1.0	6.9	6.8	43.7
Upper Mississippi River Valley Group—														
Park Rapids	14	9.0	6.5	9.1	5.4	0.9	0	0	0	0.2	1.4	7.4	6.3	46.2
Lake Winnibigoshish	14	8.6	6.5	9.9	3.3	0.8	0	0	0	T.	1.0	7.8	7.8	45.7
Sandy Lake Dam	14	9.0	9.5	10.6	3.6	0.7	0	0	0	0.2	1.1	7.4	7.4	49.4
Lake Superior Group—														
Mt. Iron	13	9.9	7.8	11.2	3.9	1.1	0	0	0	0.1	0.8	8.1	11.6	54.4
Duluth	25	10.3	9.1	11.1	4.0	1.0	0	0	0	0.1	0.3	8.2	8.7	52.8
Lower Mississippi River Valley Group—														
La Crosse, Wis	15	8.4	8.7	6.6	1.4	T.	0	0	0	T.	0.1	3.9	8.9	37.1
Grand Meadow	14	8.0	9.8	9.9	3.1	0.4	0	0	0	T.	0.3	5.3	9.3	46.1
St. Charles	9	7.7	9.4	9.5	2.4	0.2	0	0	0	0	0.1	4.3	9.3	42.9
Red Wing	8	8.0	5.6	4.4	1.8	0.2	0	0	0	T.	0.3	1.5	7.1	28.9
St. Paul	24	7.7	6.2	8.8	3.6	0.2	0	0	0	T.	0.2	4.7	5.7	37.1
Lower Minnesota River Valley Group—														
Shakopee	14	7.7	8.1	7.8	1.9	T.	0	0	0	T.	0.4	3.0	4.6	33.5
St. Peter	13	5.5	6.1	7.1	0.7	T.	0	0	0	0	0.4	1.4	4.0	25.2
Winnebago	10	6.5	7.5	6.3	1.0	T.	0	0	0	T.	0.3	2.3	6.5	30.4
Middle Mississippi River and St. Croix Valleys Group—														
Minneapolis	18	8.3	8.6	9.5	4.0	0.2	0	0	0	T.	0.3	4.5	6.4	42.4
Collegeville	14	6.7	5.6	8.5	1.8	0.4	0	0	0	T.	0.3	3.5	5.0	31.8
Pine River Dam	14	9.1	8.4	9.5	2.8	0.8	0	0	0	0.1	0.6	5.9	6.8	44.0
Osceola, Wis	11	9.1	8.4	11.7	2.8	T.	0	0	0	T.	0.1	5.5	6.8	44.4
Grantsburg, Wis	11	9.2	9.0	12.2	4.2	0.1	0	0	0	0	0.1	8.5	8.9	52.2
Upper Minnesota River Valley Group—														
New Ulm	14	8.9	7.5	9.5	1.7	0.2	0	0	0	T.	0.3	3.5	4.4	36.0
Bird Island	14	4.7	5.8	6.0	1.5	0.4	0	0	0	T.	0.5	3.5	3.4	25.8
Milan	14	7.5	8.1	11.2	1.6	0.5	0	0	0	T.	0.6	4.1	6.1	39.7
Minnesota River Watershed Group—														
New London	14	4.6	4.2	7.0	1.7	0.1	0	0	0	0	0.3	2.7	3.4	24.0
Long Prairie	14	5.7	5.5	7.4	2.4	0.4	0	0	0	T.	0.2	3.3	4.4	29.3
Morris	14	5.2	5.4	7.8	2.1	0.5	0	0	0	0	0.6	3.2	4.4	29.2
Fergus Falls	13	6.2	5.7	7.6	2.8	0.4	0	0	0	T.	1.0	5.7	5.8	35.2
Southwestern Group—														
Fairmont	13	5.0	10.0	8.8	1.9	0.1	0	0	0	T.	0.2	3.9	5.3	35.2
Worthington	13	4.1	7.2	7.6	1.2	T.	0	0	0	0	0.3	2.7	3.6	26.7
Lynd	14	6.3	5.1	7.4	2.8	0.5	0	0	0	T.	1.2	2.8	5.3	31.4
Gary, S. D	11	4.4	6.6	12.4	4.5	0.2	0	0	0	T.	1.2	4.2	4.1	37.6

83 per cent at 7 a. m. and 72 per cent at 7 p. m. Table IX gives the monthly and annual data.

Number of rainy days.—In Table X the number of rainy days during each month and the year is given for thirty-three stations well distributed over the State. The smallest number is 64 at Lynd, Lyon County, and the largest 132 days at Duluth.

Sunshine.—The sunshine is abundant, averaging from 43 to 53 per cent of the highest amount possible. The daylight hours are materially longer during the crop-growing season in the northern portion of the State than in the southern. The greatest percentage of sunshine is in the southwestern portion and the least in the northeastern part.

Table VII. Prevailing Wind Direction

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Year
Lake of the Woods Group—														
Tower	9	nw.	w.	nw.	w.	w.	w.	w.	w.	w.	w.	w.	nw.	w.
Red River Valley Group—														
St. Vincent-Pembina	23	nw.	nw.	nw.	nw.	nw.	se.	s.	se.	nw.	nw.	nw.	nw.	nw.
Crookston	14	s.	nw.	s.	n.	nw.	s.	sw.	se.	nw.	s.	s.	nw.	s.
Moorhead	28	nw.	nw.	nw.	n.	n.	se.	s.	se.	se.	se.	nw.	nw.	n.
Upper Mississippi River Valley Group—														
Park Rapids	16	nw.	nw.	nw.	nw.	s.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
Lake Winnibigoshish	16	nw.	nw.	w.	nw.	nw.	w.	w.	w.	w.	nw.	nw.	nw.	nw.
Sandy Lake Dam	14	nw.	nw.	nw.	se.	e.	e.	nw.	nw.	s.	nw.	nw.	nw.	nw.
Lake Superior Group—														
Mt. Iron	14	nw.	n.	n.	n.	n.	s.	s.	n.	s.	s.	nw.	nw.	n.
Duluth	38	sw.	nw.	ne.	ne.	ne.	ne.	ne.	ne.	ne.	ne.	sw.	sw.	ne.
Lower Mississippi River Valley Group—														
La Crosse, Wis	36	s.	s.	n.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
Grand Meadow	15	nw.	nw.	nw.	nw.	nw.	se.	s.	s.	s.	sw.	nw.	nw.	nw.
St. Charles	13	nw.	nw.	se.	se.	nw.	se.	se.	nw.	s.	se.	nw.	nw.	nw.
Red Wing	12	nw.	nw.	nw.	se.	e.	se.	sw.	w.	e.	w.	nw.	nw.	nw.
St. Paul	38	nw.	nw.	nw.	nw.	se.	se.	se.	se.	se.	se.	nw.	nw.	se.
Lower Minnesota River Valley Group—														
Shakopee	14	nw.	nw.	nw.	se.	se.	nw.	nw.	nw.	se.	nw.	nw.	nw.	nw.
St. Peter	13	nw.	nw.	nw.	nw.	nw.	nw.	se.	nw.	s.	nw.	nw.	nw.	nw.
Winnebago	9	nw.	nw.	nw.	nw.	se.	se.	se.	se.	se.	se.	nw.	nw.	nw.
Middle Mississippi River and St. Croix Valleys Group—														
Minneapolis	18	nw.	nw.	nw.	nw.	ne.	s.	s.	s.	s.	s.	nw.	nw.	nw.
Collegeville	14	nw.	nw.	nw.	s.	nw.	sw.	s.	nw.	s.	nw.	nw.	nw.	nw.
Pine River Dam	16	nw.	nw.	nw.	nw.	nw.	w.	w.	nw.	nw.	nw.	nw.	nw.	nw.
Osceola, Wis	11	s.	s.	n.	n.	s.	s.	s.	s.	s.	n.	n.	s.	s.
Grantsburg, Wis	11	nw.	nw.	sw.	se.	ne.	sw.	sw.	sw.	sw.	nw.	nw.	nw.	nw.
Upper Minnesota River Valley Group—														
New Ulm	14	nw.	nw.	s.	s.	s.	s.	s.	s.	nw.	nw.	nw.	nw.	nw.
Bird Island	16	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
Milan	14	nw.	nw.	nw.	se.	se.	se.	nw.	se.	nw.	nw.	nw.	nw.	nw.
Minnesota River Watershed Group—														
New London	14	nw.	nw.	nw.	se.	se.	se.	se.	se.	se.	se.	nw.	nw.	se.
Long Prairie	14	nw.	nw.	nw.	se.	se.	nw.	nw.	se.	se.	nw.	nw.	nw.	nw.
Morris	17	nw.	nw.	s.	s.	s.	s.	s.	s.	s.	s.	n.	s.	s.
Fergus Falls	13	nw.	nw.	nw.	se.	se.	se.	nw.	se.	nw.	nw.	nw.	nw.	nw.
Southwestern Group—														
Fairmont	15	nw.	nw.	nw.	nw.	nw.	s.	s.	nw.	s.	nw.	nw.	nw.	nw.
Worthington	13	nw.	nw.	nw.	s.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
Lynd	14	nw.	nw.	nw.	nw.	se.	nw.	sw.	nw.	nw.	sw.	nw.	nw.	nw.
Gary, S. D	11	nw.	nw.	nw.	sw.	se.	se.	se.	s.	ne.	sw.	nw.	nw.	nw.

Table VIII. Average Hourly Wind Velocity in Miles

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Duluth	5	14.3	14.2	15.0	15.1	15.2	11.6	11.3	12.0	12.7	13.9	14.1	14.2	13.6
Moorhead	19	10.3	10.5	11.3	12.0	10.7	10.0	8.3	8.4	10.4	10.4	10.1	10.0	10.2
St. Vincent-Pembina	15	7.7	9.4	10.0	10.7	10.0	8.7	7.5	7.5	9.1	9.3	9.5	8.9	9.2
Two Harbors	6	9.0	8 2	9.7	9.4	7.6	7.4	7.3	7.2	8.0	8.3	8.7	8.9	8.3
La Crosse, Wis	36	7.1	7.5	8.0	8.5	7.5	6.7	6.0	5.8	6.9	7.5	7.5	7.2	7.2
St. Paul	36	7.8	8.3	8.8	9.3	8.7	7.7	7.1	7.1	8.0	8.5	8.1	7.8	8.1
Minneapolis	18	11.5	11.6	12.3	12.8	12.1	10.3	9.9	9.9	11.6	11.7	11.0	11.2	11.3
Faribault	7	9.4	9.1	9.4	11.0	9.0	7.3	5.9	6.4	7.8	8.8	9.0	9.1	8.5
Collegeville	11	9.5	9.6	11.0	12.2	11.1	10.0	9.4	9.4	10.9	9.5	9.9	9.9	10.2

Table IX. Mean Relative Humidity in Degrees

Stations		Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Duluth	8 a.m.	21	83	83	81	76	76	79	79	81	82	81	83	84	81
	8 p.m.	21	77	75	71	65	64	69	65	69	71	72	76	78	71
Moorhead	8 a.m.	21	89	88	88	84	79	84	86	87	87	84	89	89	86
	8 p.m.	21	86	86	82	65	56	62	64	61	63	69	81	85	72
St. Vincent	8 a.m.	4	80	80	88	88	79	84	88	90	87	89	89	87	86
	8 p.m.	4	83	86	88	77	58	66	71	70	71	78	89	89	77
La Crosse, Wis.	8 a.m.	21	83	82	79	74	75	79	81	85	85	81	81	83	81
St. Paul	8 a.m.	21	84	84	81	75	75	79	79	83	83	81	81	83	81
	8 p.m.	21	76	75	68	55	54	58	55	56	60	63	69	76	64
Minneapolis	8 p.m.	7	83	79	76	66	66	67	65	68	72	73	79	83	74

Table X. Number of Days with 0.01 Inch or More of Precipitation

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Lake of the Woods Group—														
Tower	9	5	4	6	5	8	9	10	8	10	7	5	5	82
Red River Valley Group—														
St. Vincent-Pembina	25	7	6	7	7	8	11	10	9	8	7	7	7	94
Crookston	14	4	4	5	6	8	10	8	8	6	5	3	4	71
Moorhead	28	8	9	8	9	11	12	10	9	8	8	7	8	107
Upper Mississippi River Valley Group—														
Park Rapids	14	8	7	10	9	11	13	11	10	9	9	7	8	112
Lake Winnibigoshish	15	6	4	7	6	10	10	9	8	7	5	5	6	83
Sandy Lake Dam	14	6	6	8	6	10	10	10	10	9	8	6	6	95
Lake Superior Group—														
Mt. Iron	14	5	4	5	5	9	11	10	9	9	7	5	6	85
Duluth	38	10	9	10	9	12	14	12	12	12	10	11	11	132
Lower Mississippi River Valley Group—														
La Crosse, Wis.	36	10	8	10	10	12	12	10	9	10	9	8	10	120
Grand Meadow	15	6	5	7	7	12	9	9	8	8	7	6	6	90
St. Charles	12	5	4	6	6	9	11	7	6	8	7	5	4	78
Red Wing	10	5	5	6	7	11	10	7	7	8	6	5	5	82
St. Paul	38	9	8	10	10	12	12	10	10	9	9	8	9	114
Lower Minnesota River Valley Group—														
Shakopee	14	5	5	7	8	11	10	9	9	9	8	6	5	92
St. Peter	12	3	3	5	6	10	9	7	7	6	5	3	2	66
Winnebago	10	4	4	6	6	12	11	9	9	7	7	3	4	82
Middle Mississippi River and St. Croix Valleys Group—														
Minneapolis	18	8	7	9	9	12	12	9	9	8	9	7	8	107
Collegeville	14	6	5	8	7	10	12	10	10	9	8	6	5	96
Pine River Dam	15	4	4	6	6	9	10	8	8	7	6	4	4	76
Osceola, Wis.	11	7	5	6	6	8	9	8	7	6	7	5	5	79
Grantsburg, Wis.	11	5	4	5	6	8	7	7	6	5	4	5	6	68
Upper Minnesota River Valley Group—														
New Ulm	14	5	5	7	7	11	11	8	8	8	7	5	4	86
Bird Island	14	4	3	6	7	10	10	8	8	8	6	5	3	78
Milan	14	6	5	7	7	9	11	8	8	7	6	5	5	84
Minnesota River Watershed Group—														
New London	14	3	3	5	5	9	9	7	6	6	5	4	3	65
Long Prairie	14	4	4	6	8	10	11	8	8	8	7	5	3	82
Morris	16	4	4	6	7	11	12	9	9	7	6	4	4	83
Fergus Falls	13	11	8	11	9	12	15	11	11	10	8	7	10	123
Southwestern Group—														
Pairmont	15	4	4	5	6	10	8	7	7	7	5	3	3	69
Worthington	13	4	4	4	6	11	10	14	8	6	5	4	4	80
Lynd	14	3	3	5	5	8	9	7	8	6	4	3	3	64
Gary, S. D.	11	3	2	3	5	6	5	6	5	4	4	3	1	47

CHAPTER III

SURFACE GEOLOGY

ROCK AREAS

The areas in which rock is so exposed as to render the land untillable are largely in the northeast quarter of the State, or along valleys in the southeast quarter. The northwest quarter is estimated to have less than 10 square miles of bare rock outcrop, and the southwest scarcely 100 square miles. It is doubtful if there is an area of 1,000 square miles in the entire State in which the plow would generally strike into rock ledges. The rock areas thus form a much smaller percentage of the State than the lake areas. The rock areas of the northeast part are chiefly rock bosses standing above the surrounding land, but the beds of the streams that lead directly down to Lake Superior are also usually on rock ledges. Among the rock knobs are some depressions covered only with moss and peaty material, glacial material being wanting, but ordinarily some glacial material is present and nearly all the land has soil enough over the bedrock to support a rich forest growth. Many of the knobs preserve the smooth surface left by the scouring effect of the ice sheet and are nearly destitute of vegetation. But certain others have become disintegrated to a depth of several inches or even to several feet from the surface and are supporting growths of vegetation of considerable density.

The rock areas of the southwest part of the State are largely of Sioux quartzite which in places comes to the surface over areas of several square miles. The rocks have scarcely enough soil over them to support the scanty vegetation. There are a few small areas of granite knobs along the Minnesota Valley from Bigstone Lake down to New Ulm. In the driftless area and part of the drift-covered area in southeastern Minnesota rock ledges of limestone and sandstone outcrop along the steep slopes of the valleys, often forming walls of considerable height. Rock is rarely exposed along the stream beds and valley bottoms. The uplands and the higher parts of the slopes of the valleys even in the driftless area usually have several feet of residuary clay and also a coating of loess or wind-deposited silt loam covering the rock formations and rendering the land tillable.

THE EARTHY MANTLE

GENERAL STATEMENT

The variety of earthy, sandy, and gravelly unconsolidated deposits which cover the rocky floor of Minnesota were formed or deposited by different agencies and at different times. They may be grouped as follows:

First. Residuary material.
Second. Wind deposits.
Third. Glacial deposits.
Fourth. Stream deposits.
Fifth. Lake deposits.

RESIDUARY MATERIAL

The residuary material, as its name implies, has been left as a residue during the breaking down or decay of the surface rocks through weathering and solution. On limestones it is usually a dark, reddish brown, gummy clay, but on sandstones and crystalline rocks it is usually granular and loose-textured. There is but a small part of Minnesota, chiefly in the southeastern counties, where residuary material is within reach of the plow. It occurs there on the upper part of the slopes of the valleys and on the narrow upland strips between valleys, but is usually covered by loess.

WIND DEPOSITS

Loess.—The wind-deposited material known as loess is largely a fine silt loam, which forms the surface in an area in the southeast part of the State embracing much of Goodhue, Olmsted, Wabasha, Winona, Fillmore, and Houston counties and parts of Mower, Dodge, Rice, and Dakota counties. It covers a small tract in the southwest part of the State in Rock, southern Pipestone, and western Nobles counties. In the southeastern counties it rests in part on glacial drift deposits and in part on the residuary clay and rock formations of the driftless area. In the southwestern part it covers glacial deposits. In the southeast district its border is very irregular, there being long strips of loess-covered land projecting westward or northwestward into the region free from loess, and also long strips free from loess extending eastward into the loess-covered tracts. The condition there is such as might result from the presence or absence of vegetation giving different degrees of protective power from the wind; areas with dense vegetation being able to hold dust that settled from the atmosphere while bare ones allowed it to be gathered up and carried on.

Wind-blown sand.—Wind-blown sand is also an important deposit. It embraces a district east of the Mississippi from Minneapolis up to Brainerd. It is narrow above St. Cloud, but below that city extends eastward to the St. Croix River. The sand does not, however, cover the entire surface in this area. Where present it rests upon glacial deposits. It has low ridges seldom 20 feet and usually 10 feet or less in height.

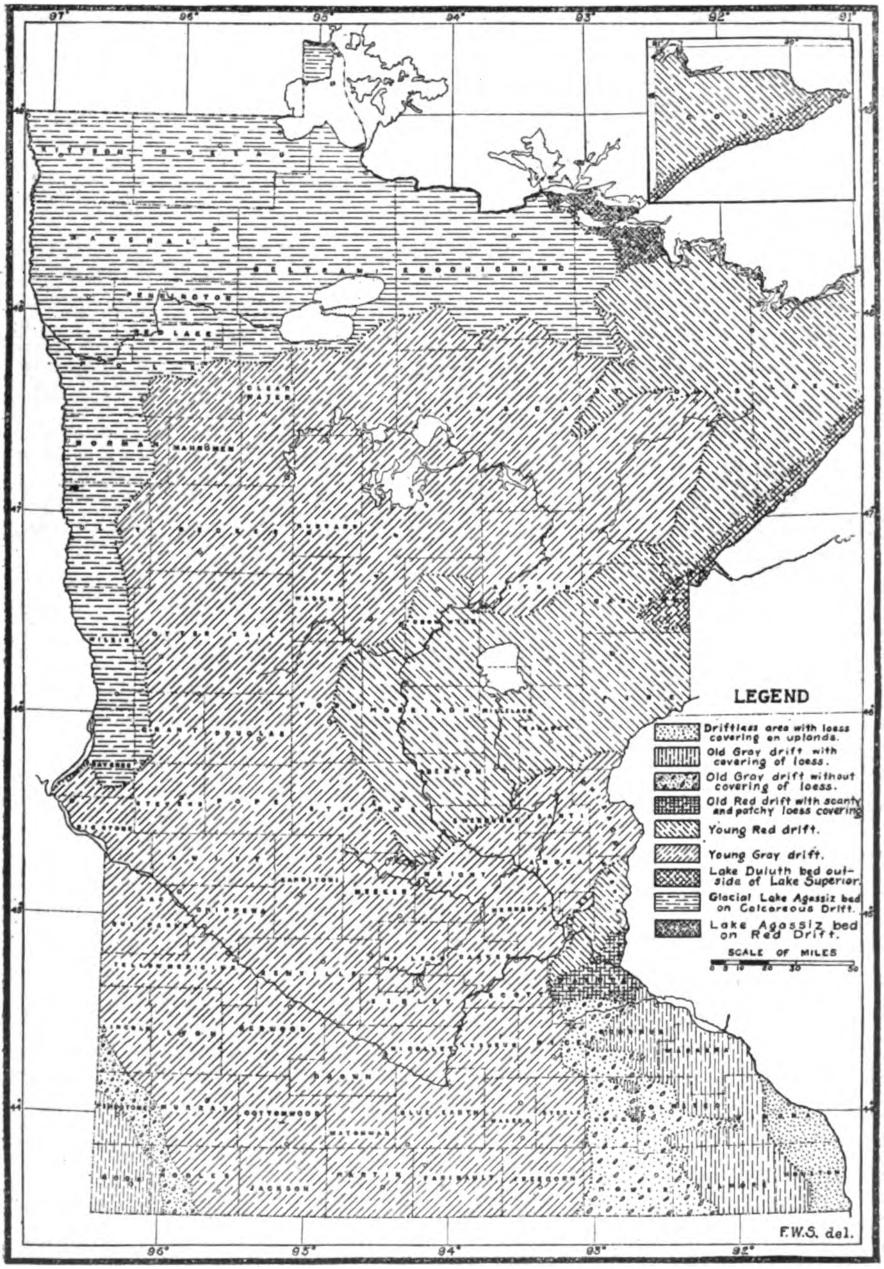


FIGURE 13. MAP SHOWING DISTRIBUTION OF GLACIAL DRIFT LOESS AND GLACIAL LAKES IN MINNESOTA BY FRANK LEVERETT

There is more or less wind-drifted sand in the sandy parts of the St. Louis River Drainage Basin, but it is sparingly developed compared to that in the district between the Mississippi and St. Croix rivers. Wind-blown sand occurs also in Aitkin County in the vicinity of McGregor and also in the northeastern part of the county in island-like tracts that are surrounded by marshes. There are numerous small areas of such sand scattered over the State, some of them being along the shores of the glacial Lake Agassiz.

GLACIAL DEPOSITS

The glacial deposits extend over the entire State except eastern Winona County and the greater part of Houston County, which are in the driftless area of the upper Mississippi. They underlie the wind-deposited sands and much of the loess area. They also underlie stream deposits and lake sediments. The glacial deposits are separable into till or bowlder clay in which stones, clay, and sand are closely commingled, and into sand or gravel beds which show some assorting and bedding by water action. The percentage of stony material varies greatly and the matrix also shows variations from compact clay to loose sand. These variations are to be expected in a deposit that had been formed from the dirt and stones included in an ice sheet. Every observing farmer has probably noted and perhaps speculated upon the cause for these variations in the drift deposits which form the basis for so large a part of the Minnesota soil. The assorted sand and gravel beds are largely due to waters escaping from the melting ice and many of them may be traced up to a moraine which marked the position of the ice border at the time they were laid down. They show a decrease in coarseness in passing away from the edge of the moraine, the coarse material having been dropped close to the edge of the ice and only the fine carried to a great distance outside.

The glacial deposits also show some variations that relate to the kind of rock formations over which the ice passed. Thus, the northeastern portion of the State has a rather stony drift from the volcanic and hard crystalline rocks of that region. This stony material was carried as far south as Dakota County and forms the red drift of eastern and northeastern Minnesota. The western and southern parts of the State have a large amount of clayey drift material with limestone pebbles imbedded. This material was gathered by this ice as it passed across in its southward course from the shales and limestone of southern Manitoba, that greatly dominate there over the granite and other crystalline rocks. These clayey and limy deposits form what is known as the gray drift of Minnesota.

STREAM DEPOSITS

The stream deposits, being restricted to the valleys, are of limited area, though in such valleys as the Minnesota and Mississippi they are locally several miles in width and form important agricultural belts. On the Minnesota and the part of the Mississippi below the confluence with the Minnesota the deposits made by the rivers are sand or silt. On the Mississippi above the mouth of the Minnesota the deposits range from sand to coarse cobble and bowlders in correspondence with the swiftness of the stream. On nearly all the tributaries of the Mississippi and Minnesota the streams are able to carry coarse as well as fine material. Along the Red River a considerable amount of fine clay and clay loam has been deposited in seasons of flood on the plains outside the immediate river channel. Because of the flatness of the surface many of the small tributaries of Red River have been unable to maintain courses clear through to the river, and so have dropped their deposits where the gradient became too low for the stream to carry them farther. The deposits made by glacial streams or those which had their sources at the edge of the ice and were receiving much of their water from the melting ice, now appear usually as terraces along the valleys above the limits of floods. From the fact that the glacial rivers were of greater volume these deposits are generally composed of sandy and gravelly material somewhat coarser than that carried by the present rivers.

LAKE DEPOSITS

The lake deposits consist of fine sediments washed into the deep parts of the lakes and sandy and pebbly deposits washed up and formed into beaches along the shores. In parts of the lakes where the glacial deposits which they covered were pebbly and the water was shallow enough for wave action, there was a concentration of stony material by the washing-out of the finer material. By this process considerable areas of the bed of Lake Agassiz were covered by very pebbly beds several inches in depth. They are classed on the map of northwestern Minnesota as "lake-washed till." In the narrow strip along the shore of Lake Superior that was covered by the waters of a glacial lake known as Lake Duluth, gravelly and cobbly beaches were formed at several successive levels, while fine material was washed down into the deeper parts of the basin covered by the present lake.

In the Red River Basin and to a slight extent at the west end of the Superior Basin there are fine sediments of considerable depth which had a close relation to the melting ice and yet are not in all places clearly separable from the lake sediments of later date. While including masses of till or bowlder clay and nests of bowlders, they are largely of fine silt which was laid down at the ice margin in the lake where the ice

A. RIVER SCENE AT ROSEAU, MINNESOTA

B. WHEAT FIELD ON CLAY PLAIN ON BED OF LAKE AGASSIZ

C. HOMESTEAD ON CLAY PLAIN ON BED OF LAKE AGASSIZ

sheet terminated. The supply of material in such cases was from the ice instead of from the washing-in of material from the land outside. The great brickyards at Wrenshall in Carlton County obtain their material from silt deposits of this sort.

THE GLACIAL FEATURES

It has been found through a study of the deposits in Minnesota and neighboring states that the glacial deposits which form so extensive a mantle in Minnesota are the result of more than one invasion of the ice from the Canadian highlands. At each invasion the ice left a deposit of drift gathered partly from Canada and partly from the deposits over which it passed in Minnesota. The advances were so widely separated in time that the drift deposits of one invasion had large valleys cut in them by the action of streams before the next invasion occurred. The later advances failed to cover some parts of the earlier deposits, so they are still exposed to view, and the degree of erosion of the surface of the older can be compared with that on the surface of the younger deposits. It is found that the older drift deposits have been so greatly eroded and are so ramified by drainage lines that no lakes or undrained basins remain on them, while the younger drift deposits have numerous lakes and undrained basins and also large, poorly drained areas which the streams have not yet reached. It is because they are not covered by the latest drift that Rock and Pipestone counties in southwestern Minnesota, and Goodhue, Dodge, Wabasha, Olmsted, Winona, Fillmore, and Mower counties in southeastern Minnesota have no lakes and basins such as characterize neighboring counties that were covered by that drift.

The invasions of the ice into Minnesota not only took somewhat different paths but have come from more than one direction. In the earlier invasions the greater part of the State was covered by ice coming from Manitoba as shown by limestones derived from rock formations of that country which are imbedded in the lower part of the drift over all of the State except its northeast part, and also in the drift of western Wisconsin. The movements in the closing stage of the glacial epoch were more largely from the northeast, there being an extension of ice southwestward from the Superior Basin nearly to Mille Lacs Lake, and an extensive southward movement from the highlands northwest of Lake Superior to points a little beyond St. Paul. But even in this closing stage the ice from Manitoba covered much more than half of the State and on the melting-away of the ice that came from the northern highlands extended over some of the ground that ice had vacated. This is known from the presence of a thin deposit of clayey and limy drift containing rock material brought from Manitoba over parts of the drift that was deposited by ice coming from the highlands northwest of Lake Superior. The drift from these highlands together with that from the Lake Superior Basin forms the stony red drift of eastern Minnesota, while that from Manitoba forms the clayey and limy gray drift which covers almost all of the remainder of the State.

That the ice mass moved in different directions at different times in certain parts of the State is further shown by striations or ice markings on the surface of the rock ledges. In the district east and south of the Lake of the Woods a set of glacial grooves or ice markings bears west of south, while a newer set crosses them in an eastward or southeastward direction. The older set was formed by ice moving into Minnesota from the highlands that lie between Lake Superior and Lake Winnipeg, while the younger set was formed by ice moving into the State from Manitoba. In North Minneapolis there are rock ledges on which the glacial grooves have three courses; first, a southeastward course at the time when the old gray drift which came from the northwest was brought in; second, a southward course at a time when the red drift which came from the north was deposited; third, an eastward course at the time when the ice from the northwest advanced over land that had been vacated by the ice which deposited the red drift.

GLACIAL LAKE FEATURES

Minnesota contains parts of the beds of two large glacial lakes: Lake Duluth, which occupied the western part of the Superior Basin, and Lake Agassiz which occupied the Red River Basin. Lake Duluth covered a narrow strip along the shore of Lake Superior and extended a few miles beyond the west end of Lake Superior into eastern Carlton County, Minnesota. Its highest stages were about 500 feet above the present surface of Lake Superior. Lake Agassiz extended as far south as Lake Traverse, where it discharged past Brown Valley to the Minnesota. Its border is only from 20 to 30 miles east from the North Dakota-Minnesota line from Lake Traverse northward to Polk County. About 20 miles east-southeast of Crookston it makes an abrupt eastward turn and continues eastward past the south side of Red Lake and on across Koochiching County into St. Louis County as far as the valley of Little Fork River. It then turns northward and enters Canada from northeastern St. Louis County. There were several islands in it in northern St. Louis County.

The western or prairie portion of this lake area was studied by Warren Upham[1] some thirty years ago, and his monograph on the glacial

---

[1] Monograph XXV, U. S. Geological Survey.

Lake Agassiz contains a large body of important data on this region. In this monograph an island, called Beltrami Island, is represented to cover a large area north of Red Lake. This, however, is now known to have been covered by Lake Agassiz, its highest points being bars of gravel and sand in the lake.

There were also small glacial lakes in other parts of Minnesota where waters were temporarily ponded in front of the ice. These will be mentioned in the description of the counties. None of them, however, fall within the limits of the northwest quarter of the State.

The most prominent features of the two great glacial lakes, Lake Agassiz and Lake Duluth, are the beaches or ridges of sand and gravel washed up along their shores. The shores of Lake Agassiz stand high and dry above the flat parts of the lake bed between or below them and form excellent lines for highways. For this reason much of the pioneer settlement and travel was along these ridges. They generally stand from 5 to 10 feet above the bordering plains and occasionally from 15 to 20 feet. On the inner or lakeward side they are generally more prominent than on the outer or landward side. This is due in part to the original slope toward the center of the lake, but there is also a tendency for a lake to eat back into the bordering land and throw its coarser material up on the edge of the plain outside; at the same time the fine material is carried in suspension from the shore into the deeper water.

The levels of these glacial lakes were lowered from time to time, partly by the cutting-down of the outlets and partly by an uplift of this region which caused the water to fall away where the land rose. There was also a change of outlet in Lake Agassiz from the southern end to the northern and in Lake Duluth from the southward outlet into the St. Croix River to an eastward outlet into the Lake Huron Basin. As a result shore lines were formed at various levels on the slopes of the old lake beds. As a result of the gradual lowering of the water level the greater part of the beds of these glacial lakes has at some time been subjected to wave action. This has produced a widespread pebbly coating which is a concentrate from the washing of the surface of the bowlder clay and the carrying-away of its finer material. Where the bowlder clay was sandy, the sand as well as stones remain, but where it was clayey there is often a clear bed of pebbles a few inches in depth covering the clayey till subsoil. The deep part of Lake Agassiz along the borders of Red River received nearly all the fine sediment which was washed out from the till at higher levels. This forms the bulk of the rich black clay and clay loam of the Red River Basin. At its eastern border 15 to 25 miles from Red River there is a transition to sand. This is succeeded within 2 to 5 miles east by stony sandy deposits which seem to be a glacial material worked over by the lake.

CHAPTER IV

GENERAL SOIL CONDITIONS

Soil is composed of materials derived from the subsoil and mixed with organic matter. Subsoil is the weathered and disintegrated top of the subjacent geological formation. For its qualities and composition the soil of a given region therefore depends quite closely upon the nature of the geological formations there exposed. In Minnesota the land mantle of glacial and lake deposits affords a well-mixed and rich supply of materials suited for soil-making. This is particularly true where it consists of till or bowlder clay in which all classes of material are loosely but thoroughly mixed. This contrasts with soils in which there is too much uniformity and which, when of water-washed sand or gravel, are often deficient in fine material. On the other hand, the loess and the lake silts, though of somewhat uniform texture, make rich soils because of the variety of finely divided minerals which they contain.

The soil and its productiveness depend largely upon the drainage conditions. A soil of clay or clay loam over gravel or loose sand suffers in time of deficient rainfall, while a soil resting upon heavy clay may be drowned out unless surface drainage is perfectly adjusted. For this reason the geologic formation underlying a soil is of great importance. Soil underlaid by limestone, by loess, or by a till consisting of a light clay, or a heavy loam will stand great variation in rainfall and still be highly productive. In some parts of the State the surface drainage is naturally well developed, while in other parts it needs to be greatly supplemented by tile draining or surface ditching.

In the Driftless Area the drainage is everywhere complete, for nearly every acre slopes toward some drainage line. In the old drift also there are few undrained areas and tiling or surface ditching is seldom necessary. In the young drift there are many basins, and undrained depressions and drainage lines are not well distributed over the surface. Except, therefore, where the material is loose enough for the rainfall to be absorbed completely the young drift areas need considerable ditching and tiling. In the bed of Lake Agassiz, although basins and depressions are rare, there are wide areas in which the surface is very flat and extensive and systematic ditching is required to keep the land from being flooded.

VEGETATION

The condition of the soil depends to some degree upon the character of the vegetation which has covered it. In prairie districts there is a more uniform exposure to weathering agencies than in forested districts

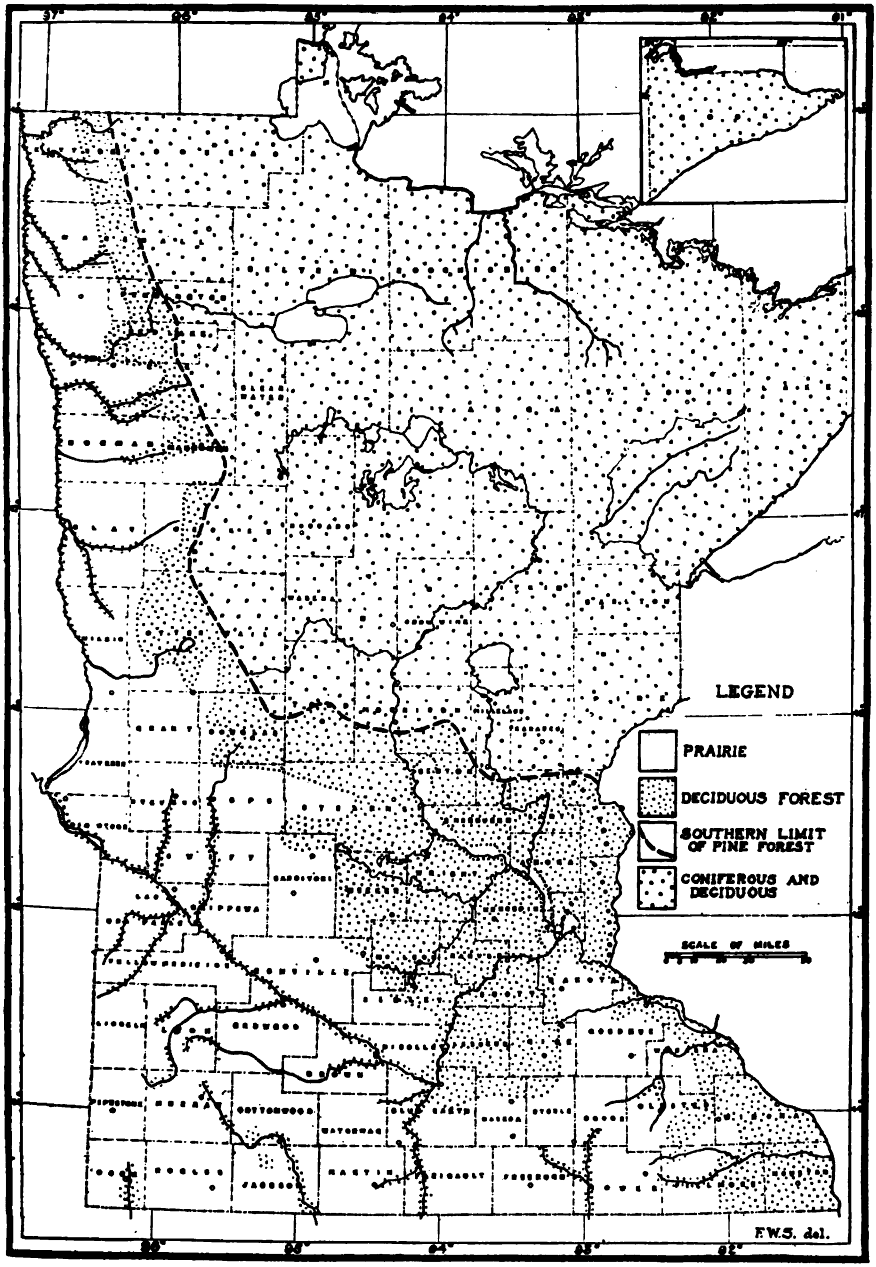


FIGURE 14. MAP OF MINNESOTA SHOWING DISTRIBUTION OF FOREST AND PRAIRIE. (AFTER MAP BY WARREN UPHAM AND BY FREDERIC K. BUTTERS)

and consequently a more uniform soil is developed on a given deposit. On the whole, leaching of lime seems to be less rapid on prairies than in forests so that in the newer drift limestones are often present at the surface in prairies, but in the forested areas limestones are usually dissolved out to a depth of some inches and often to some feet from the surface. On the older drift the limestone is generally removed to a depth of several feet both in prairie and forest, but the leaching is perceptibly deeper in the forested areas. The rate of erosion and removal of soil is more uniform in prairie than in forested tracts. It takes more force to dislodge the trees than the grassy vegetation on hillside slopes, and erosion in the forests is likely to become concentrated in occasional gullies, whereas on prairies there are many small channels developed on every hillside which serve to break it down rapidly. On the whole, therefore, erosion is greater but leaching is less in prairie than in forested areas.

The forests occur only on protected slopes in much of southern Minnesota and are absent from such slopes in much of the western part of the State (Fig. 14). In the central and northeastern parts they cover plains or uplands as well as valley slopes. The muskegs, which have a scanty forest growth, are developed chiefly in the northern half of the State and chiefly within the forested area.

WEATHERING

There are parts of the newer drift in which fresh material is close to the surface so that they can scarcely be said to have a subsoil different from the drift sheet as a whole. There are also places on valley slopes in the older drift where unweathered material is close to the surface, because erosion keeps pace with the weathering of the drift. At most places, however, the older drift has a mantle of weathered material several feet in thickness, while that of the younger drift is only one or two feet thick. In this the feldspar and other minerals are disintegrated and made ready for plant food.

Weathering in the loess-covered areas is moderately deep, as it is in the older drift. The entire deposit of loess, however, is of fine texture and is found to be very fertile from top to bottom.

LIME

While most of the soils of the northwestern part of the State seem abundantly supplied with lime, it is probable that some of the more sandy ones would give a sufficiently greater yield of certain crops to make it profitable to purchase some form of lime if this could be obtained at a low price. Usually when a soil needs lime, it is advisable to apply one ton or more of ground limestone or marl per acre. If this has to be shipped any considerable distance, the freight charges may greatly exceed the cost of the material on board of the cars at the point of shipment. For this reason it is important to locate a supply as near as possible to the place where it is to be used.

Lime occurs abundantly in two forms in Minnesota: as bog-lime or marl, and as limestone. The marl is unconsolidated and easily pulverized. It needs no crushing or grinding. Limestone is consolidated and must be crushed or ground for use on fields.

Marl is found in Minnesota in many lakes and under some bogs that have been lakes. It is of most frequent occurrence in the central and north central part of the State. It lies always in low wet ground and can be found, as a rule, only by boring or ditching. It is a soft, white or gray, chalky material. Since it needs no crushing or grinding, the cost of the marl is in the finding, ditching and draining, or drying of it. Deposits from 1 to 10 feet in thickness and covering from 1 to 100 acres are known to be of common occurrence.

Limestone formations outcrop in the bluffs along the Mississippi and its tributaries in southeastern Minnesota. The formations lie horizontally and are of wide extent, or practically continuous for many miles. Limestone formations 100 feet or more thick extend along the valleys from the southeastern corner of the State to Stillwater, Minneapolis, Mankato, Austin, and intermediate points. An inexhaustible supply of limestone is easily found in outcrops that are high, so that quarrying, crushing, and loading can all be done in a down-hill direction, the cost of production being thereby lessened.

CHAPTER V

AGRICULTURAL CONDITIONS AND LAND CLASSIFICATION IN THE NORTHWEST QUARTER OF MINNESOTA

GENERAL STATEMENT

The area embraced in this report covers northwestern Minnesota as far eastward as the 94th meridian and southward to the median line of the State which is near latitude 46° 25′. It embraces about 24,000 square miles outside of Lake of the Woods. The greater part is tributary to Hudson Bay, only 5,600 square miles being tributary to the Mississippi River. Nearly all of this Hudson Bay drainage lies in the bed of the glacial Lake Agassiz. The altitude has a range of about 1,000 feet, or from 750 to 1,750 feet, the highest points being around the head of the Mississippi River. The western part is prairie and the eastern forested land, the line between forest and prairie being from 20 to 40 miles east of Red River. The rainfall ranges from 21 to 28 inches, being lowest on the western border and increasing toward the southeastern.

Settlement began earlier on the prairie portion. Indeed, much of the forested portion still remains unoccupied. Likewise large swamp areas, chiefly in the eastern part of the bed of Lake Agassiz, await artificial drainage before they can be occupied. Four of the great railway systems, the Northern Pacific, Great Northern, Soo Line, and Canadian Northern, have lines traversing northwestern Minnesota and render the greater part of it readily accessible.

In general the supply and quality of well waters throughout the region is good. This region also embraces very extensive flowing well areas in parts of the Red River lowland and in other low areas farther east.

Valuable data on the extent of swamp areas, the direction in which swamps may be most easily drained, and other matters pertaining to drainage conditions, may be obtained from the reports of the State Drainage Commission, from topographic sheets of parts of Ottertail and Becker counties by the United States Geological Survey, and from a report and map of a drainage survey of lands in the region south of Lake of the Woods, published as House Document 27, Sixty-first Congress, First Session. These reports and maps have been of much service in preparing the estimates presented below.

DESCRIPTIONS OF COUNTIES

In the descriptions of counties the first county taken is in the northwest corner of Minnesota, and following this, counties to the east, thence south to the southeast corner of the area embraced in this report, and

A. TILL PLAIN IN MAHNOMEN COUNTY

B. WHEAT FIELD ON TILL PLAIN IN MAHNOMEN COUNTY

thence westward to the southwest corner. General observations concerning settlement and utilization of the land and a few data from the census of 1910, as well as the results of the land classification on a geologic basis, are presented.

KITTSON COUNTY

Kittson County is the northwest corner county of Minnesota and lies entirely within the limits of the glacial Lake Agassiz. As a consequence the classes of land are restricted to lake deposits and lake-washed glacial deposits, though the swamps are covered to considerable extent by peat. The following percentages of each class of land have been computed from field maps. Their distribution in the county may be seen by reference to the general map (Plate I) accompanying this report.

Percentages of Classes of Land in Kittson County

	Sq. miles	Per cent of county
Black clay and clay loam, lacustrine	463	41.7
Sandy deposits of old lake shores	175	15.7
Stony or pebbly sandy loam, lake-washed drift	270	24.3
Stony or pebbly clay loam, lake-washed drift	130	11.7
Swamp land	73	6.6
Totals	1,111	100.0

The black clay and clay loam of the Red River Valley, being a highly productive soil with no forests to remove, has naturally been the first to be taken up for farms. The part of the stony clay loam which borders the black clay loam on the east has also been largely settled and brought into cultivation. Its texture being looser than that of the black clay loam, it is more easily cultivated. The only drawback to cultivation is the presence of surface bowlders which in parts of the area are numerous. They are especially abundant north of Orleans and in the northeast part of the county between Hemmington and Caribou, and in the eastern part north of Pelan. They do not greatly encumber the land in the southeast part of the county or in the district southeast of Orleans.

The areas of stony sandy loam have a variable soil ranging from sandy to gravelly and embracing many patches of clayey drift. The large ditches which traverse the area show abrupt changes from bowlder clay to sand or gravel. In places bowlder clay underlies the sandy gravel at a depth of from only 3 to 5 feet. Such areas and those with a bowlder clay soil are as productive as either of the clay loams. But on the whole the spotted character renders this class of soil somewhat inferior to the areas of clay loam. The land is very thickly strewn with bowlders in the district between Bronson and Pelan, and is still largely in a wild state. The areas in the northeast part of the county and northeast of Bronson have only a moderate number of bowlders. They embrace much wet land which is as yet only partially drained by artificial ditches.

The sandy land varies greatly as to agricultural conditions. The old shore lines are rather barren because of the relief which they have above the bordering plains and consequent depth of the water table. The sandy plains, for a few miles from the western edge, are generally underlaid by clay at very slight depth and thus have a water table sufficiently near the surface to supply moisture for the crops. In fact some of the sandy land on the immediate border of the black clay loam, as already noted in the general discussion of the region, is preferred as farm land because of its loose texture and easy cultivation. In the northern part of the county the sandy land is so interspersed with marshes that systematic ditching will be necessary to render it suitable for farming. There is an area of sandy land extending from Bronson southward past Halma to the county line with large numbers of surface bowlders, a rather rare feature on so sandy a soil. The presence of the bowlders indicates that the sand may be largely of glacial deposition. The productiveness of the deposit is also greater than in the ordinary lake sand. It is extensively cultivated for potatoes and other root and vegetable crops.

The swamp lands in the eastern part of the county generally have peat and black muck to a depth of from 3 to 6 feet or more, beneath which there is usually a clayey glacial deposit. The swamps in the northern part are more generally underlaid by sand.

Farm and Crop Data for Kittson County from the Census of 1910

Percentage of land area in farms................	52.3
Percentage of farm land improved..............	77.2
Average acres per farm.........................	307.5
Average improved acres per farm...............	237.5
Value of all farm property......................	$13,730,520.00
Percentage of gain since 1900...................	110.3
Average value of a farm.......................	$11,348.00
Cereals produced in 1909.......................	$2,043,887.00
Other grains and seeds..........................	$91,269.00
Hay and forage.................................	$179,805.00
Vegetables	$41,007.00
Fruits and nuts.................................	$727.00
All other crops.................................	$17,400.00
Total crop production in 1909..................	$2,374,095.00

It should be noted that the prices of farm lands have made a marked advance since 1910, so that the average value for the bare land in 1914 is likely to be nearly $40.00 per acre, and for land with improvements fully $50.00 per acre. The black clay loam of the western part of the county will probably now average nearly $75.00 per acre, if the land carries with it good buildings and improvements.

The most complete settlement is on the black clay loam and the neighboring tracts of sandy land and stony clay loam in the western part of the county, and in the southeast part of the county along the Soo Railroad. But farms are rapidly being developed over the remainder of the county and the large swamps are being drained preparatory to settlement.

ROSEAU COUNTY

Roseau County lies next to the Manitoba line and extends from Kittson County to Lake of the Woods. It is entirely within the limits of the glacial Lake Agassiz and consequently has soils formed from lake deposits or from lake-washed glacial deposits. There is, in its northwestern part, a considerable area of lake clay and clay loam with black soil similar to, and yet isolated from, the area of black clay loam of the Red River Valley. The greater part of the county has soils formed on lake-washed glacial material. Old shore lines and associated sands are, however, conspicuous in the southeastern part of the county, and such a shore line is followed by the Great Northern Railroad from Greenbush nearly to Roseau. There are very extensive swamps in the northern and the southeastern parts of the county on which considerable ditching has been started preparatory to settlement. A great body of first-class land extends from the southwest part of the county northeastward past Roseau to the south fork of Roseau River.

The following estimated percentages of each class of land were computed from field maps. The general map accompanying this report (see Plate I) sets forth their distribution.

Percentages of Classes of Land in Roseau County

	Sq. miles	Per cent of county
Black clay and clay loam, lacustrine	170	10.2
Sandy deposits of old lake shores	210	12.6
Stony or pebbly sandy loam, lake-washed drift	270	16.1
Stony or pebbly clay loam, lake-washed drift	470	28.1
Swamp, largely peat covered	550	33.0
Totals	1,670	100.0

Much of the area of black clay loam in the northern part of the county is under cultivation and it not only supports the three settlements around Pine Creek, Ross, and Duxby, but adds materially to the prosperity of Roseau, the county seat. The areas of stony and pebbly clay land are also very largely under cultivation both in the district southwest from Roseau and that south of Warroad and Swift, but are more slowly developing in the district southeast of Roseau between Falun and Wannaska. Bowlders seldom impede cultivation of the soil.

In the vicinity of America and Clear River there are good farms with sandy soil covering a clay subsoil. In places the sand is so thin that bowlders of the glacial material are only partly covered. In the southwestern part of the county, south from Greenbush, on each side of the Great Northern Railway, the land is very spotted, some farms being largely of pebbly clay loam and others chiefly sandy or gravelly loam. There are also areas of clear sand and gravel extending to the depth of the ditches, 3 to 5 feet or more.

The southeastern borders of the county embrace areas of productive land among the swamps, but much ditching and road-building is necessary there in order to make conditions suitable for successful farming. The areas of lake sand over water-laid moraine (marked on map "*LS over MW*") have a base of glacial material of variable constitution thinly veneered with sandy lake material. In places the bowlders of the glacial formation are visible, though usually they are concealed by the sand.

The swamps of this county form an almost complete barrier to communication with Manitoba, so that customs officials are needed only at Pine Creek and Warroad. A large amount of systematic ditching will be necessary to prepare this swamp for settlement. The amount of peat over much of this area is so great that it presents a forbidding outlook. Yet swamps similar to this, when the water is removed, and intelligent farming methods are employed, often are made to yield profitable returns.

Farm and Crop Data for Roseau County from the Census of 1910

Percentage of land area in farms................	29.5
Percentage of farm land improved..............	49.9
Average acres per farm.........................	196.7
Average improved acres per farm................	98.2
Value of all farm property.....................	$6,135,882.00
Percentage of gain since 1900..................	176.3
Average value of a farm........................	$3,830.00
Cereals produced in 1909.......................	$430,443.00

Other grains and seeds	$111,428.00
Hay and forage	$163,021.00
Vegetables	$64,523.00
Fruits and nuts	$270.00
All other crops	$49,271.00
Total crop value	$818,956.00

Farm land prices have made a material advance since 1910, much of the good land now being held at from $40.00 to $50.00 per acre.

MARSHALL COUNTY

Marshall County lies immediately south of Kittson and Roseau counties. It extends about 70 miles east from Red River and has a width from north to south of 25.5 miles. The area, as given in the census of 1910, is 1,788 square miles. It is wholly within the limits of the glacial Lake Agassiz and its classes of land are therefore restricted to lake deposits and lake-washed glacial deposits. Much of the stony clay loam land was poorly drained and was classed as swamp land before artificial drainage was established. But only a small part of it has a peaty cover and on that the peat is but a few inches in depth. This land, when properly ditched, can scarcely be distinguished from the areas that were originally classed as dry land. The swamp land with peat cover lies mainly along the northern edge of the county east from the Soo Railroad. There are smaller areas east and south of Mud Lake, and others among the sand ridges east of Viking. The peaty swamp land, however, is estimated to occupy only about 10 per cent of the area of this county.

The following percentages of each class of land have been computed from field maps, and their distribution is shown on the general map (Plate I).

Percentages of Classes of Land in Marshall County

	Sq. miles	Per cent of county
Black clay and clay loam, lacustrine	450	25.2
Sandy deposits, of old lake shores	315	17.6
Stony or pebbly sandy loam, lake-washed drift	175	9.8
Stony or pebbly clay loam, lake-washed drift	665	37.2
Swamp land	183	10.2
Totals	1,788	100.0

The large body of pebbly clay loam in this county, when given proper drainage, will probably be as productive as the black clay and clay loam of the Red River Valley. In fact its texture is looser than that of the deposits of the Red River Valley, and it is being converted into farm land as fast as the drainage work is completed. Bowlders are numerous only in small strips and patches and nowhere do they greatly impede cultivation of the soil.

The large water-laid moraine which extends from the north side of Thief Lake southwestward along the west side of Thief River has a stony or pebbly clay loam soil very similar to that of the plain to the east, and has therefore been included in this class of land in the above estimate. Its chief difference, so far as agriculture goes, is one of natural drainage, there being a more rapid escape of water from it than from the plain. Its slopes, however, are so gradual as to be scarcely perceptible to the eye, and its surface is nearly as free from knolls as that of the bordering plains.

The sharp ridges of sandy gravel, marking shore lines of Lake Agassiz, are very conspicuous features in two main belts which run across the county west of Thief River. These ridges are excellent lines for highways, and will supply plenty of material for graveling railways and highways. But they have lower productiveness because of their relief above the bordering plain, which is often as much as from 10 to 15 feet. The sandy plains among and west of the western belt of ridges have generally a light soil easily affected by drouth. There is, however, a strip 1 or 2 miles wide along the border next to the black clay of Red River Valley in which the soil is more productive.

The areas of stony and pebbly sandy loam vary greatly in degree of fertility because of variability in constitution and in drainage conditions. They include small areas of good clay loam but are usually of loose texture. These areas are much less affected by drouth than the sandy areas and include a number of good farms.

Farm and Crop Data for Marshall County from the Census of 1910

Percentage of land area in farms	49.6
Percentage of farm land improved	67.0
Average acres per farm	267.7
Average improved acres per farm	179.5
Value of all farm property	$16,952,344.00
Per cent of gain since 1900	99.6
Cereals produced in 1909	$2,313,218.00
Other grains and seeds	$230,560.00
Hay and forage	$328,798.00
Vegetables	$72,664.00

Fruits and nuts	$1,372.00
All other crops	$40,171.00
Total crop value	$2,986,783.00

PENNINGTON COUNTY

Pennington County was organized from a part of Red Lake County in 1910 and has an area of 607 square miles. It lies immediately south of the eastern part of Marshall County and is entirely within the limits of the glacial Lake Agassiz. Consequently its soils are all from lake deposits and lake-washed glacial deposits. Its western end has considerable light sandy soil connected with some of the lower beaches of Lake Agassiz, but the central and eastern parts of the county have heavier soil and there are also strips of heavy soil between the sandy strips in the western third of the county.

A large water-laid moraine runs southward across the county on the west side of Red Lake River. But it has been so covered with the beach material that the glacial deposits of which it is composed are exposed only on the eastern or outer slopes of the moraine for a short distance west of Red Lake River and the lower course of Thief River. These glacial deposits are of pebbly clayey material like that underlying the plains farther east. Low swells from 3 to 5 feet high are present on the outer slopes, some of which are to be seen within the limits of the city of Thief River Falls. The slope on the outer face is barely perceptible to the eye, as it amounts to scarcely 20 feet in a distance of from 1 to 2 miles.

In the central and eastern part of the county no definite beaches or ridges of sandy gravel occur to break the monotony of the plain. The prevailing material is a lake-washed pebbly clay loam, but in nearly every township there are numerous small areas of sand and fine gravel and also small swamps filled with peat nearly to the level of the bordering dry land. Large ditches opened in this district show abrupt changes from pebbly clay to sandy, gravelly, and peaty deposits and the peat is found in some cases to be 5 feet or more in depth. There are a few low swells standing 5 feet or less above the bordering plain, and these as a rule are found to be composed of glacial material, usually a pebbly clay. Not infrequently a strip of gravel comes in between the clay and the peat as one passes from the dry ground into the swampy land.

Farm and Crop Data for Pennington County from the Census of 1910

Area of county in square miles	607
Percentage of land area in farms	66.3

Percentage of farm land improved	53.1
Average acres per farm	207
Average improved acres per farm	109.9
Value of all farm property	$6,326,149.00
Cereals produced in 1909	$548,253.00
Other grains and seeds	$100,726.00
Hay and forage	$208,626.00
Vegetables	$41,791.00
Fruits and nuts	$817.00
All other crops	$22,923.00
Total crop value	$923,136.00

As in Marshall County the extensive ditching and heavy assessment for draining the wet areas have tended to keep down land prices. Yet the land is increased in value far beyond the expenditure in draining it.

This county is being covered by a detailed soil survey under the Bureau of Soils of the United States Department of Agriculture. The work is in charge of W. G. Smith. In this detailed study, there is of course a more refined analysis and classification of soils than has been attempted by the present writer in the survey of the glacial and lake deposits of this region. This will be brought out in a report by the Bureau of Soils. In the present report and accompanying map (Plate I) Mr. Smith has endeavored to group soils to correspond with the classes shown in the other counties. The percentages of the different classes of soil are based entirely upon the work of the Bureau of Soils and estimated by Mr. Smith.

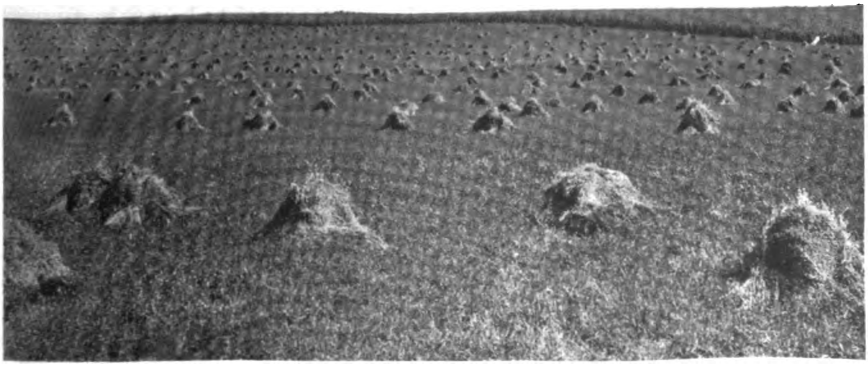
STATEMENT BY W. G. SMITH

The western third of the county has been open to settlement something over thirty years, while the remaining eastern portion was opened to settlement only ten years ago.

There is a somewhat uniform but rather sparse settlement all over the county, scarcely half of its area being in farms and less than one third under cultivation. Settlement and enlarging of cultivated acreage seem to be extending rapidly. The land would easily support a much larger population, for it is nearly all of good quality.

The sandy deposits of the old lake shores ("sand ridges") were settled first, as they were not subject to standing water that remained for a long time on the lower lying lands following wet seasons. Since the installation of large drainage ditches throughout the county most of the land is sufficiently protected against standing water to permit of use for farm purposes at all times. Some additional ditching would bring practi-

A. HOMESTEAD ON CLAY MORAINE IN OTTERTAIL COUNTY



B. OATS (AND CORN IN BACKGROUND) ON CLAY MORAINE IN OTTERTAIL COUNTY

cally the whole area of the county within the range of possible use for farm purposes.

Percentages of Classes of Land in Pennington County

	Sq. miles	Per cent of county
Sandy deposits of old lake shores	14	2.3
Stony or pebbly sandy loam, lake-washed drift	128	21.1
Stony or pebbly clay loam, lake-washed drift	368	60.6
Swamp (peat land)	97	16.0
Total	607	100.0

Nearly three fifths of the area of the county has stony or pebbly loam to clay loam surface soils with clay subsoils. Such lands have high agricultural value and under proper cultural methods they have the capacity of producing the staple crops under a wide range of moisture conditions.

About one fifth of the area of the county is covered by sandy loams and loams underlaid by sandy and gravelly subsoils of various depths. While in places the lands are somewhat subject to overdrainage and otherwise show less resistance to drouth than soils having clay subsoils, they should prove to be well suited to agricultural purposes under good cultural methods.

Treeless swamps and peat lands occupy a little less than one fifth of the area of the county. Adequate drainage is one of the first essentials to bring this character of land within the range of usefulness for field-crop purposes. The depth of peat varies considerably, from a few inches to 5 feet or more. The greater depths are found in the east and southeast portions of the county, where the larger areas of peat or swamp lands occur. Some of the townships there have nearly half of their areas covered with swamp or peat. While these areas are not extensively farmed, the staple crops seen growing on peat in some places give the impression that ultimately these peat lands will be subdued to a stage where they may be depended upon to produce profitable crops under a wide range of seasonal variations.

RED LAKE COUNTY

Red Lake County lies south of Pennington and is bordered on the west, south, and east by Polk County. It is traversed by Red Lake River from which its name was derived, as it does not touch upon Red Lake. Since Pennington County was cut off from it there remains an area of only 432 square miles. It is entirely within the limits of the glacial Lake Agassiz, and thus is restricted in soil classes to lake deposits and lake-washed glacial material. There is a strip of light sandy land on its west border in connection with some of the lower shore lines of Lake Agassiz. The borders of Red Lake Valley, of Clearwater Valley and of its main tributaries, Lost, Hill, and Poplar rivers, have generally a sandy or sandy loam soil, but the greater part of the county has a pebbly clay loam soil, much of which is sufficiently well drained to be suitable for cultivation. There are few places where bowlders are so numerous as seriously to impede cultivation. Some of the sandy land along Clearwater and Red Lake rivers, in the vicinity of Red Lake Falls, is underlaid at slight depth by a lake clay and the sand itself is exceedingly fine-textured. Land of this class is as productive as any in the county. The swamp land is chiefly in the eastern end of the county, and has usually a thin growth of peat over glacial material of variable constitution, with abrupt changes from sand or gravel to pebbly clay.

The following percentages of each class of land have been computed from field maps, and their distribution may be seen on the accompanying general map.

Percentages of Classes of Land in Red Lake County

	Sq. miles	Per cent of county
Sandy and silty lake and stream deposits	110	25.4
Pebbly sandy loam, lake-washed drift	45	10.4
Pebbly clay loam, lake-washed drift	250	58.0
Swamp	27	6.2
Total	432	100.0

There is a somewhat uniform but rather sparse settlement all over this county, scarcely half of its area being in farms, and less than one-third under cultivation. The land would easily support double or treble its present population for it is nearly all of good quality.

Farm and Crop Data for Red Lake County from the Census of 1910

Percentage of land areas in farms	45.4
Percentage of farm land improved	61.5
Average acres per farm	238.0
Average improved acres per farm	189.8
Value of all farm property	$3,711,300.00
Cereals produced in 1909	$363,671.00
Other grains and seeds	$79,828.00
Hay and forage	$94,537.00
Vegetables	$24,028.00
Fruits and nuts	$119.00
All other crops	$12,180.00

POLK COUNTY

Polk County, of which Crookston is the county seat, lies south of Marshall and Red Lake counties, and extends from Red River eastward nearly 70 miles. Its area, as given by the census of 1910, is 1,980 square miles. Its greatest width is at the west in Red River Valley, and nearly half its area has the lacustrine black clay and clay loam. An area of about 500 square miles in the southeastern part lies outside the limits of the glacial Lake Agassiz.

A survey and map of the southwestern part of the county, around Crookston, has been made by the Bureau of Soils of the United States Department of Agriculture.[1] It is chiefly in the area of black clay and clay loam bordering Red River, but its eastern part extends up over some of the lower beaches and associated sandy strips of Lake Agassiz. The northeast part of the map includes a few square miles of stony sandy loam (Benoit fine sandy loam and Benoit loam), a glacial deposit modified more or less by lake action. In the eastern part there are very bowldery areas of lake-washed pebbly clay, classed in part as Benoit loam and in part as Sioux gravelly loam. They are very different from the lake beaches which are composed of sandy gravel and are classed as Sioux gravelly sandy loam. It has been found necessary, therefore, in the present map to depart somewhat from the soil map, in this eastern part of the Crookston area, and make a clear distinction between the lake beaches and the bowldery plain. A large part of the Fargo fine sandy loam of the Crookston area soil map is a deposit such as in other counties of the present report has been classed and represented on the map as lake sand. It has a light soil easily affected by drouth and requiring intelligent cultivation.

The classes of land represented in Polk County include two types of land-laid moraine, the sandy and the clayey, and plains of till or pebbly clay loam, which like the moraines stand above the limits of the glacial Lake Agassiz. The moraines are of a pronounced knob and basin type with numerous small lakes, ponds, and swampy depressions among the knolls and ridges. The till plains are also diversified by small lakes and ponds occupying shallow basins. A few of these are capable of drainage at moderate expense, but the majority have beds below the neighboring drainage lines. Some of the lakes have been partly and others almost completely filled by peaty growths. The extensive swamps are chiefly in the northeastern part of the county on the plain covered by Lake Agassiz, those outside the limits of the old lake being usually too small to admit of representation on the small scale here adopted.

---

[1] Mangum, A. W., and Schroeder, F. C., Soil survey of the Crookston area, Minnesota: Field operations of the Bureau of Soils 1906.

There is a large peaty swamp in the southwest part of the county across which Sand Hill River discharges by the aid of artificial ditches.

The percentages of the several classes of land here given are based upon field maps and the soil map of the Crookston area. Their distribution is shown on the general map.

Percentages of Classes of Land in Polk County

	Sq. miles	Per cent of county
Sandy moraine	86	4.3
Clayey moraine	73	3.7
Clayey till plain	265	13.4
Sandy soil in till plain	10	0.5
Lake-washed sandy till, pebbly sandy loam	60	3.0
Lake-washed clayey till, pebbly clayey loam	230	11.6
Sandy deposits of old lake shores	305	15.4
Lacustrine black clay and clay loam	835	42.2
Swamps and small lakes and ponds	116	5.9
Totals	1,980	100.0

The wild land in Polk County is found chiefly in the sandy areas and swamps and in the roughest or most hilly parts of the moraines, the first-class land being nearly all in farms. The land outside the limits of Lake Agassiz has about as productive a soil as the clay loams of the old lake area and more productive than the sand and light sandy loams of the lake area. This statement is made since there is a widespread impression that the fertility of northwestern Minnesota land is due to its having once been a lake bed, and it might be inferred that there is a markedly lower degree of fertility outside the lake area. The character of the soil is of course less uniform than in the part of the old lake bed immediately bordering Red River. It is necessary also in a district where ponds and lakes and small peaty basins occur to allow for a considerable percentage of waste land. But the tillable land of southeastern Polk County is a close rival in fertility to that of the Red River Valley. In this part of the county wheat was, for a time, the sole important crop, but now diversified farming is coming into vogue.

Farm and Crop Data for Polk County from the Census of 1910

Percentage of land area in farms	70.2
Percentage of farm land improved	72.4
Average acres per farm	252.2

Average improved acres per farm	182.7
Value of all farm property	$34,946,027.00
Percentage of increase since 1900	78.5
Average value of a farm	$9,914.00
Cereals produced in 1909	$4,216,361.00
Other grains and seeds	$331,471.00
Hay and forage	$670,551.00
Vegetables	$212,600.00
Fruits and nuts	$5,355.00
All other crops	$134,195.00
Total crop value	$5,570,593.00

There has been some advance in farm prices since 1910, so that the average value of an improved farm with good buildings may be not less than $50.00 per acre, while farms of this sort in the Red River Valley approach $75.00 per acre.

CLEARWATER COUNTY

Clearwater County was organized in 1903 from the southwest part of Beltrami County and has an area of 1,019 square miles. It is bordered on the west by Pennington, Polk, and Mahnomen counties and on the north and east by Beltrami County. Its northern part extends into the Red Lake Indian Reservation and its southwestern part into the White Earth Reservation. About one fourth of the county, at its northern end, is within the limits of the glacial Lake Agassiz. Its drainage is principally to Clearwater River, from which the county receives its name, but it also includes the headwaters of the Mississippi River and the State Reservation around Lake Itasca.

The portion of this county within the limits of Lake Agassiz is very largely undrained swamp land. Much of it is in the Red Lake Indian Reservation. Notes concerning the character of this swamp land have been furnished by Mr. A. P. Meade of the United States Geological Survey, who in 1913 made a survey for a topographic map of these wet lands. For a few miles along the extreme edge of the area covered by Lake Agassiz there is a sandy to gravelly loam with till of very variable constitution at slight depth and noted on the map *LST*. Farther out there is a general coating of peat over a clayey glacial deposit with local patches of sand and gravel, as in the part of Pennington County adjoining it on the west.

The part of the county outside the limits of Lake Agassiz is largely tillable land, its character being similar to that of the adjoining part of Polk County. It includes both the sandy and clayey moraines and extensive till plains of a prevailingly clayey constitution. There are numerous small lakes and swamps among the morainic knolls and ridges, and also scattered lakes and shallow swampy basins in the till plains. It is difficult to estimate the aggregate amount, but probably not less than 20 per cent of the area of the moraines and till plains of this county are water and waste land, which is not taken into account in the table below. There are extensive swamps in the southern part of the county extending out in all directions from Rice Lake, and others farther north in the vicinity of Bagley and Shevlin which are included in the swamp land in the table.

The percentages of the several classes of land here given are based upon field maps and to some extent on the notes by Mr. Meade. Their distribution is shown on the general map.

Percentages of Classes of Land in Clearwater County

	Sq. miles	Per cent of county
Sandy moraine, with sandy to gravelly loam soil....	173	17.0
Clayey moraine, with pebbly clay loam soil........	180	17.6
Clayey till, with pebbly clay loam soil.............	208	20.4
Till plain with sandy patches....................	30	3.0
Outwash gravel, and glacial drainage deposits.....	71	7.0
Lake-washed till, largely loose-textured...........	97	9.5
Sandy gravel of lake shores......................	20	2.0
Swamps and small lakes and ponds...............	240	23.5
Totals	1,019	100.0

The lightest soils of the county are found in the outwash gravels and lines of glacial drainage and in the beaches of sandy gravel on the shore of Lake Agassiz. They are composed very largely of sand and fine gravel with only a slight amount of loam in the soil. The sandy moraines usually have a considerable admixture of loam with the sand and gravel which gives them a somewhat higher degree of fertility than the outwash plains and beaches. Portions of them, however, are greatly interrupted by small swamps and deep basins which render cultivation of the land rather difficult and in consequence only a small part of this land has been brought under cultivation. The wet lands of the northern portion of the county lie largely in the Red Lake Indian Reservation, but outside the reservation are very sparsely settled. They need considerable ditching to render them tillable. The areas of clayey moraine and clayey till which constitute about three eighths of the county have highly productive soils, but as yet only a small portion of the land is improved. Settlement is more or less retarded from the fact that it is a forest-covered tract.

Farm and Crop Data for Clearwater County from the Census of 1910

Percentage of land area in farms	26.8
Percentage of farm land improved	23.2
Average acres per farm	165.5
Average improved acres per farm	38.4
Value of all farm property	$3,150,087.00
Cereals produced in 1909	$146,906.00
Other grains and seeds	$3,940.00
Hay and forage	$128,655.00
Vegetables	$39,659.00
Fruits and nuts	$461.00
All other crops	$65,326.00
Total crop value	$384,947.00

BELTRAMI COUNTY

Beltrami County extends from the Lake of the Woods southward past Red Lake to the line of Hubbard County. The south boundary is about 100 miles from the southernmost point on Lake of the Woods. There is also a small detached area known as the Northwest Angle lying west of Lake of the Woods whose northernmost point is about 135 miles from the Hubbard County line. In its widest part the county embraces nine ranges of townships or 54 miles. The census of 1910 gives the county an area of 3,822 square miles. This evidently does not include Red Lake and probably does not include the small lakes inside the county. The total area of Red Lake is 440 square miles, of which 408 square miles fall within the townships and ranges embraced in Beltrami County. The small lakes embrace about 100 square miles. The sum of the sections and parts of sections outside of Red Lake is 3,924 square miles. If 102 square miles are allowed for the small lakes, the land area is reduced to what is given by the census report, or 3,822 square miles. In the estimates of percentages given below it has been found necessary to include the small lakes as has been done in other counties, not only for the sake of uniformity, but also because it is not possible in some cases to draw the line between lake and swamp. The lakes and swamps are accordingly grouped together, and the percentages are estimated on the basis of an area of 3,924 square miles.

The greater part of Beltrami County lies within the limits of the glacial Lake Agassiz, whose southern shore passes along the south side of Red Lake. As already noted, it was once supposed that a part of Beltrami County north of Red Lake stood above the level of Lake Agassiz and was called Beltrami Island. The highest points in that district, however, have bars of sandy gravel on them formed by Lake Agassiz. A considerable part of the bed of Lake Agassiz within the limits of Beltrami County is still a muskeg swamp which can be traversed only with great difficulty except when frozen. Through the heroic efforts of Mr. Meade and his party of surveyors it was traversed sufficiently to obtain data necessary to construct the topographic and drainage map which accompanies House Document 27 of the Sixty-first Congress, First Session. Mr. Meade has also kindly furnished such information as he had gained concerning the character of the soil of the small islands that rise here and there above the level of the muskeg. Information concerning the soil on some of the islands has been obtained from Mr. A. R. McDonnell, of Baudette, who had made timber estimates on them for lumber companies and who was the present writer's guide over parts of the district. The data are thus such as were noted incidentally in the course of other investigations and should be read with this understanding. As far out as settlements have reached, the present writer gave the soil personal examination.

Data concerning soils on the Northwest Angle were obtained from Mr. E. C. Barnard of the United States Coast and Geodetic Survey, who was in charge of the survey along the boundary between Minnesota and Manitoba in 1912 and 1913. Data on islands in Lake of the Woods were kindly supplied by Mr. W. A. Johnston of the Geological Survey of Canada who cruised among them and studied their geology in the summer of 1913. Mr. Johnston also supplied notes concerning the occurrence of lake clay over glacial deposits along the shore of Lake of the Woods and in the bluffs of Rainy River in this county.

The district south of Red Lake stands above the level of Lake Agassiz, and here roads are few and much of the land is still in forest. It was not possible, therefore, to obtain such full knowledge of the soil conditions as in the districts to the west where forests have been cleared and farms opened. Diligent inquiry was made, however, throughout this part of the county, of residents who had some personal knowledge of the character of the land.

Nearly all the rock outcrops of this northwest quarter of Minnesota are in the northern part of Beltrami County. They occur here and there for several miles south of Rainy River and Lake of the Woods, as well as on islands in Lake of the Woods, but their aggregate area is estimated to be only 8 square miles. Usually a rock knob on the mainland occupies only an acre or two, but there are a sufficient number to amount to a square mile or more of bare rock. On the islands in Lake

VIEWS ON GRAVEL OUTWASH PLAIN NEAR WADENA

UNIV. OF MICH.

of the Woods much of the surface is bare rock except Garden Island. This, Mr. Johnston reports, is thickly covered with a calcareous bowlder clay, and it derives its name from its having been cultivated to some extent.

Percentages of Classes of Land in Beltrami County

	Sq. miles	Per cent of county
Sandy moraine, with sandy to gravelly loam soil....	145	3.7
Clayey moraine, with pebbly clay loam soil........	170	4.3
Outwash gravel, and sandy glacial drainage deposits	216	5.5
Till plains with prevailingly clay loam soil.........	393	10.6
Till plains with mixed soil, sandy to clayey.......	72	1.8
Stony or pebbly clay loam, lake-washed drift.....	292	7.4
Stony or pebbly sandy loam, lake-washed drift.....	266	6.7
Sandy and gravelly deposits of old lake shores....	207	5.0
Lake clay	23	0.6
Rock outcrops................................	8	0.2
Small lakes..................................	102	2.5
Swamp land..................................	2,030	51.7
Totals	3,924	100.0

The settlements in the northern part of the county are chiefly within 10 miles of the Canadian Northern Railroad, and even here only a small percentage of the land is cleared and cultivated. There are a very few residences along Rapid River and Rainy River, and a few scattered over the high tract of gravel and sand from 12 to 15 miles south and southwest of Williams.

There are prosperous settlements in the district northwest of Red Lake, with post-offices at Malcolm, Thorhult, Jelle, Carmel, and Orheim. Grain and produce is marketed at Thief River Falls though this point is distant fully 50 miles from the eastern part of this farming district. Large ditches have been made and others are in course of construction which will give the region fair drainage. The soil is largely a pebbly clay loam, strewn thickly in places with bowlders, but generally supplied with only a sufficient number to provide foundations for buildings. The roads, which usually follow the lines of the ditches and utilize the embankments, are in good condition for hauling heavy loads to the distant market. This district had only a scattered and stunted forest cover so that it has been easier to bring it into cultivation than the heavily forested areas south of Red Lake.

In the part of the county south of Red Lake farming is chiefly carried on in the areas of pebbly clay loam and gravelly areas near Bemidji and south and west from that city. There is very little settlement as yet between Bemidji and Red Lake. There are small settlements along the eastern border near Kelliher, Funkley, Black Duck, and scattered settlers southward past Louis to the border of Cass Lake. The prevailing soil there is a pebbly clay loam, but it is interrupted by patches of sandy or gravelly soil. Much remains to be done in ditching the land and in road-building as well as in clearing of forests to bring this district into a condition of full cultivation, but the fertility of the soil is such as to encourage such development.

Farm and Crop Data for Beltrami County from the Census of 1910

Percentage of land area in farms................	9.1
Percentage of farm land improved...............	14.9
Average acres per farm.........................	141.9
Average improved acres per farm...............	21.1
Value of all farm property.....................	$3,389,856.00
Cereals produced in 1909.......................	$56,646.00
Other grains and seeds.........................	$5,031.00
Hay and forage.................................	$127,054.00
Vegetables	$126,585.00
Fruits and nuts................................	$1,221.00
All other crops................................	$286,922.00
Total crop value...............................	$601.459.00

WESTERN KOOCHICHING COUNTY

Only the western three ranges of townships in Koochiching County, embracing an area of 1,027 square miles, will be considered in this report. It so happens that it includes the part of the county in which swamps are most extensive, and thus is not fairly representative of the county as a whole. About 80 per cent of this part of the county lies within the limits of the glacial Lake Agassiz, but about 200 square miles in the southern end stand above the highest shore line.

There are a few rocky knobs near Manitou Rapids and southwestward from there, and also near Clementson, but they aggregate scarcely a square mile in area.

The cultivable land in the portion within the limits of Lake Agassiz is mainly along the borders of the streams. In most places muskeg swamps set in within a mile back from these drainage lines. This is true even on the borders of Rainy River, in places where its valley is from 30 to 40 feet deep. There are belts of sandy land, in part moraine and in part beach or shore deposit, which cross the interstream areas and break the continuity of the muskeg swamps. On one of the sandy strips near Wayland a few settlers have located. There are also a few in the vicinity of Norden, on the borders of Tamarack River, and on sand ridges to the south. Only small clearings have as yet been made by any of the settlers, and the narrowness of the cultivable strip will greatly restrict farming operations under present conditions of drainage. Several good county roads are projected across these swampy districts, and some are in process of construction.

In the portion of this county above the level of the highest shore of Lake Agassiz a large percentage of the land is tillable with but small expenditure for ditching, and this portion of the county is being developed rapidly. The soil is mainly a pebbly clay loam, but there are morainic strips in which gravelly and sandy knolls occur, and the soil is generally loose-textured, though quite productive.

Percentages of Classes of Land in Western Koochiching County

	Sq. miles	Per cent of area
Sandy moraine, with sandy to gravelly loam soil....	54	5.2
Till plain, with prevailingly clay loam soil.........	146	14.2
Stony or pebbly clay loam, lake-washed drift......	114	11.1
Sandy and gravelly deposits of old lake shores.....	57	5.6
Rock knobs..................................	1	0.1
Swamp land..................................	655	63.8
Totals	1,027	100.0

NORTHWESTERN ITASCA COUNTY

An area of about 470 square miles in the western three ranges of townships in Itasca County will be discussed in this report. The south part is included in the Minnesota National Forest, and is uninhabited. The remainder is a very sparsely populated district, there being few farms except in the vicinity of the Minnesota and International Railroad, which crosses the northwest corner of the county. Much of this district is practically inaccessible unless one forces his way through brush and swamp, there being very few roads or trails across it. Considerable information has, however, been obtained in reference to it from residents who have had occasion to go into this district.

Aside from a morainic strip which runs southeastward from Orth past Island Lake to Popple, this district seems to be occupied entirely by till plains and swamps. It is thought, however, that the wet land may be easily drained when the brush is removed and a moderate amount of ditching is done. The soil appears to be subject to abrupt changes from clay to sand or gravel, and the designation *TM* on the general map stands for mixed soil in a till plain. Of the 470 square miles fully 80 per cent is in the till plain. The sandy moraine occupies about 7 per cent. There thus remains about 10 to 12 per cent in lakes and swamps.

PARTS OF CASS AND CROW WING COUNTIES

The greater part of Cass and a few townships in the northwest part of Crow Wing County fall in the southeast part of the area embraced in this report. It is made to include the whole of the three townships southeast of the Mississippi River in Crow Wing County since they extend but a slight distance outside the limits of the map. But north of the Mississippi the estimates do not extend east of Range 27, as only a small part of Range 26 is within the limits of the map. In making the percentage estimates of the different classes of land Leech Lake and Winnibigoshish Lake are not included. Leech Lake has an area of 173 square miles at low-water stage and Winnibigoshish an area of 77 square miles. The smaller lakes of this district are estimated to have an aggregate area of about 177 square miles and the swamps 133 square miles. There is thus 560 square miles of lakes and wet land or about 25 per cent of the entire district. But counting out Leech and Winnibigoshish lakes and thus reducing the district 250 square miles, the lakes and swamps comprise 15.6 per cent, of which 8.9 per cent is lake and 6.7 per cent swamp. The area of the district as thus reduced is 1,990 square miles.

This district is separable into several distinct belts. At the north, along the south side of the Mississippi River and Winnibigoshish Lake, there is a plain of sandy gravel with forest of Norway pine which extends south about to the line of the Great Northern Railroad. South of this on the borders of Leech Lake is a great till plain with a pebbly clay loam soil to the northwest of the lake, and with a mixed or variable soil to the east and southeast. Extensive tracts of wet land are present on the plain east of Leech Lake. On the immediate south border of this lake there is a rolling country with stony or pebbly clay loam soil. This changes on the south into a more sandy and gravelly tract of moraine which covers several townships of this district and extends westward in a broad belt across Hubbard County to the headwaters of the Mississippi in Clearwater County. This moraine loses expression, however, toward the east side of the district under discussion and consists of scattered groups of knolls bordered by nearly plain tracts of mixed clay and sand and gravel. From Whitefish Lake southward to Gull Lake and eastward to the Mississippi is a gravelly glacial outwash plain with numerous basins containing lakes. The strip of gravelly glacial outwash extends from Whitefish Lake northwestward past Backus along the south side of the great moraine just mentioned. The morainic tract has an offshoot to the south from near Hackensack which separates this gravelly outwash plain from a larger one in Hubbard and Wadena counties. In the southwest part of the district are several townships with gently undulating clayey moraines and bordering till plains. The till plains are in part clayey and in part have mixed soil with abrupt and frequent changes from pebbly clay to gravel or sand. In the extreme southeast part of this district on the east side of the Mississippi there is a rugged sandy moraine with small outwash gravel plains included among groups of morainic knolls.

Percentages of Classes of Land in Parts of Cass and Crow Wing Counties

	Sq. miles	Per cent of district
Sandy moraine, with sandy to gravelly loam soil...	379	19.0
Clayey moraine, with pebbly clay loam soil........	191	9.6
Outwash gravel plains..........................	540	27.1
Clayey till plain, with pebbly clay loam soil........	205	10.2
Till plain with mixed soil, clayey to sandy or gravelly	365	18.3
Swamps	133	6.7
Small lakes..................................	177	8.9
Totals	1,990	99.8

This district has farming settlements in the western part along the line of the Minnesota and International Railroad and the Great Northern Railroad which extend over the till plains and clayey moraines of the southwest part. There is also a settlement at Longville, southeast of Leech Lake. The remainder of the district is very sparsely inhabited. The soil of much of this district is rich enough to justify large expenditures in road-building and in draining the land and in clearing it of brush. The heavy soil of the till plains and clayey moraines of Cass County is well adapted for stock-raising and dairying as well as general farming. The iron mines in the southeast corner of this district have brought in a large population which gives a good home market for garden produce and dairy products of that locality.

HUBBARD COUNTY

Hubbard County is a rectangular tract seven townships long and four townships wide lying west of Cass and south of Beltrami County. It contains 1,008 square miles, of which about 93 square miles are estimated to be covered by small lakes. The census of 1910 gives the land area as 958 square miles, some of the lakes apparently being included.

The southern end of the county is occupied by a large plain of sandy gravel in which there are a number of small lakes and marshes of considerable extent. North of this is a great moraine of sandy and gravelly constitution, in which a number of lakes are included, and from which the sandy outwash of the plain to the south was derived. On its north border the moraine becomes more clayey and graduates into a till plain which occupies much of the northern third of the county. There are small areas of sandy land along the north border, one being in the northeast corner near Farris, and another a few miles southwest of Bemidji, both of which extend into the great sandy plain of the southern part of Beltrami County. The till plain has a pebbly clay loam soil and constitutes the best farming land in the county, there being several prosperous farming settlements on it. A portion of the sandy plain in the southern part of the county had no forest on it at the time the country was settled, so that farms were easily cleared and brought into cultivation. The district around Park Rapids and Hubbard was therefore settled long before the neighboring forested areas.

Percentages of Classes of Land in Hubbard County

	Sq. miles	Per cent of county
Sandy moraine, with light sandy to gravelly loam soil	267	26.5
Clayey moraine, with pebbly clay loam soil	151	15.0
Outwash gravel plains	153	15.1
Till plain, with pebbly clay loam soil	224	22.2
Small lakes	93	9.3
Swamp land	120	11.9
Totals	1,008	100.0

Farm and Crop Data for Hubbard County from the Census of 1910

Percentage of land area in farms	24.8
Percentage of farm land improved	36.6
Average acres per farm	180.3

Average improved acres per farm	66.1
Value of all farm property	$3,175,028.00
Percentage of gain since 1900	212.1
Cereals produced in 1909	$171,961.00
Other grains and seeds	$9,417.00
Hay and forage	$116,760.00
Vegetables	$89,302.00
Fruits and nuts	$1,029.00
All other crops	$74,052.00

A considerable part of the gain in value of farm property in Hubbard County is due to development of new farms. The average value of land per acre in 1900, according to the National Census, was $7.10, or slightly more than half of that of 1910. The present value of land is somewhat higher than in 1910, and may average, with improvements included, about $30.00 per acre.

WADENA COUNTY

Wadena County embraces only fifteen townships or an area of 540 square miles. Its southern edge extends 3 or 4 miles beyond the southern limits of the map accompanying this report, but the discussion embraces the whole county. The greater part of this county is a sandy outwash plain, a southward continuation of that in Hubbard County. Along the west border, however, there is a till plain with pebbly clay loam soil embracing an estimated area of 117 square miles, or, including swamps, a little more than one fifth of the county. The southern end of the county, in the vicinity of the Northern Pacific Railroad, has been settled for many years. The western range of townships, along the line of the Great Northern Railroad, has more recently been converted into farms. But in the northeast part of the county there are still very few settlers. That part of the county has considerable wet land. The entire county has been estimated by George A. Ralph to contain 80,000 acres of swamp (*Drainage Engineer's Report,* 1906).

In the part of this county south of Leaf River there was a re-advance of ice over the gravelly outwash which greatly increased the fertility by introducing clayey calcareous drift a few feet thick and mixing it with the gravel. The farms are kept in a good state of fertility by the growing of clover which thrives on this soil.

Farm and Crop Data for Wadena County from the Census of 1910

Percentage of land area in farms	46.1
Percentage of farm land improved	43.9

Average acres per farm	158.0
Average improved acres per farm	69.4
Value of all farm property	$4,697,499.00
Percentage of gain since 1900	130.00
Cereals produced in 1909	$263,978.00
Other grains and seeds	$13,170.00
Hay and forage	$136,990.00
Fruits and nuts	$486.00
All other crops	$45,269.00
Total crop production in 1909	$512,294.00

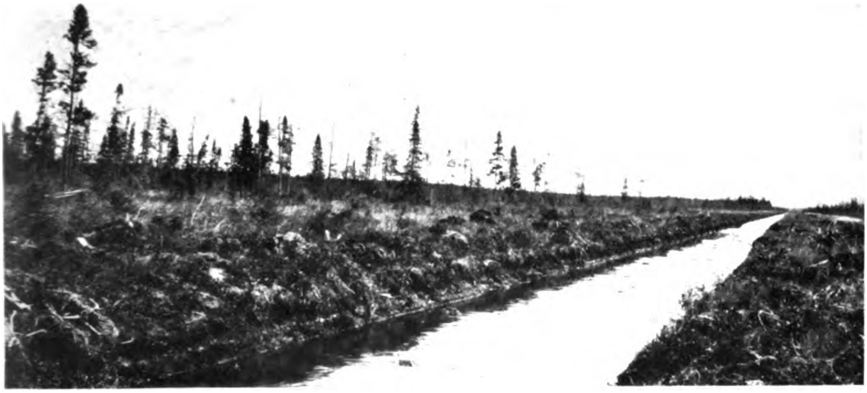
NORTHERN OTTERTAIL COUNTY

The map accompanying this report includes twenty-six full townships and parts of nine other townships in the northern part of Ottertail County. The discussion and estimates here given will cover the entire thirty-five townships or 1,260 square miles.

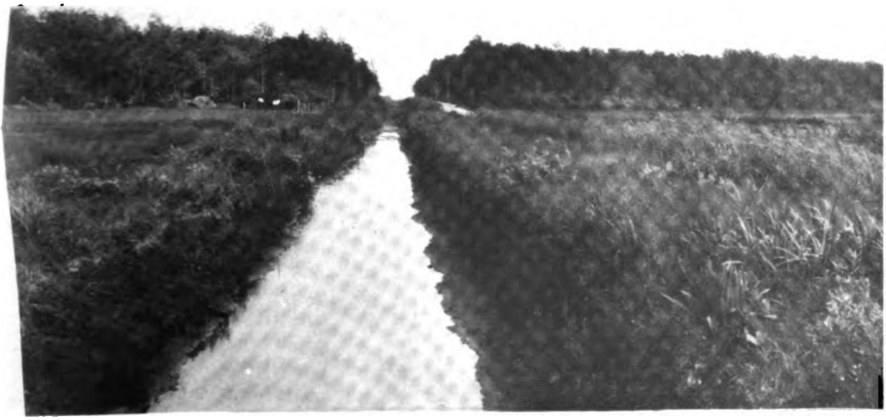
In the northeastern part of the county there is an area of about 200 square miles of till plain with a pebbly clay loam soil, parts of which are thickly strewn with bowlders. It includes a few small lakes and swamps, and, until cleared of brush, parts of it are poorly drained. The surface, however, is undulating and but a moderate amount of ditching will be required to render much of the wet area suitable for cultivation.

In the northern and central parts of the county there is a very rugged moraine of sandy constitution with local developments of clayey drift. This includes a multitude of small lakes and undrained basins which in several townships comprise nearly half the surface. Estimates of the percentages of dry and wet land made from the topographic sheets of the United States Geological Survey, are presented below. In a large part of this area of morainic drift it would be difficult to find a square mile of land free from swamp or lake, and in some townships there is scarcely a 40-acre lot free from wet land. The slopes of the morainic knolls are also steep, as may be seen by an inspection of the topographic sheets. It is an interesting fact that this morainic area with its extremely rough surface stands almost in sight of the featureless plains of the Red River Valley, a few miles to the west. Here it would be difficult to carry a straight furrow for more than a fraction of a mile, while on the neighboring plains there is nothing to turn the plow aside. This rugged district, known as the Park Region of Minnesota, seems best adapted for grazing and dairying. The soil is of sufficient strength to give good pasturage, while there is no lack of water supply for the stock.

The western limits of this rugged moraine are at the east side of



A. DRAINING A MUSKEG SWAMP IN ROSEAU COUNTY



B. DRAINED SWAMP IN PENNINGTON COUNTY WITH FOREST ON LAKE-WASHED TILL IN BACKGROUND

UNIV. OF MICH.

Pelican River Valley. To the west of that valley is a moraine of clayey constitution and more gently undulating surface. This is in places thickly set with small lakes but the amount of lake and marsh is scarcely half as great as in the more rugged moraine to the east. Almost the entire area of this clayey moraine is under cultivation and the marshy ground is utilized to a considerable extent for pasturage. This tract stands at the border between forest and prairie, only a part of its surface being occupied by forests and groves.

There is an extensive outwash plain around Ottertail Lake and Rush Lake, and lines of glacial drainage come down to it from the north. One of these is along the line of Ottertail River and the other along Toad River. In this outwash plain and the lines of glacial drainage just mentioned, lakes and basins are very numerous, as in the rugged moraine to the west, but there is a much smaller amount of swamp land than in the moraine. The dry land also has a level surface and thus contrasts strikingly with the rugged surface of the moraine. This plain varies in fertility in proportion to the amount of loam in the soil and in proportion to the nearness of the water table to its surface. The soil is, however, on the whole lighter than that of the neighboring moraines.

There are two sharp gravel ridges, termed eskers, in the northeastern part of Ottertail County, one being east of Pine Lake, and the other on the upland south of Perham. These are more winding and sharper than the shore lines of the glacial Lake Agassiz, but like the shore lines are composed of sandy gravel. Ridges of this class often occur on till plains where gravel for roads is an important asset. The ridge east of Pine Lake may thus serve a useful purpose.

Percentages of Classes of Land in Northern Ottertail County

	Sq. miles	Per cent of district
Sandy moraine, with sandy to gravelly loam soil....	258	20.4
Clayey moraine, with pebbly clay loam soil........	160	12.7
Outwash gravel and sandy glacial drainage deposits.	229	18.2
Till plain, with prevailingly clay loam soil.........	217	17.2
Lakes and swamps............................	396	31.5
Totals	1,260	100.0

The estimates of swamp land and lakes in the Perham, Vergas, Battle Lake, Underwood, and Fergus Falls topographic sheets,[1] so far as they fall within this district, have been computed section by section, and their aggregate for each township follows. The border between lake and swamp is in many cases so indefinite on the topographic sheets that separate estimates have not been made.

---

[1] These topographic sheets are obtainable at 10 cents each, or $6.00 per hundred sheets, from the Director U. S. Geological Survey, Washington, D. C.

Percentage of Lakes and Swamps in Certain Townships of Northern Ottertail County

	Sq. miles	Per cent lakes and swamps
Western third of T. 137, R. 38 W.	3.6	30
Western third of T. 136, R. 38 W.	5.6	47
Western third of T. 135, R. 38 W.	6.2	51.6
Western third of T. 134, R. 38 W.	1.7	14
T. 137 N., R. 39 W.	11.4	32
T. 136 N., R. 39 W.	5.9	17
T. 135 N., R. 39 W.	16.6	46
T. 134 N., R. 39 W.	18.9	52.5
T. 137 N., R. 40 W.	14.6	40
T. 136 N., R. 40 W.	16.2	45
T. 135 N., R. 40 W.	20.4	56.6
T. 134 N., R. 40 W.	20	55.5
T. 137 N., R. 41 W.	9.5	27
T. 136 N., R. 41 W.	14.6	40.5
T. 135 N., R. 41 W.	23.1	64
T. 134 N., R. 41 W.	12	33.3
T. 137 N., R. 42 W. (two thirds of township)	10.6	44
T. 136 N., R. 42 W. (five sixths of township)	20.9	70
T. 135 N., R. 42 W. (33 square miles)	12.8	39
T. 134 N., R. 42 W.	12.5	34.7
T. 135 N., R. 43 W. (south half)	3.6	20
T. 134 N., R. 43 W.	11.9	33
T. 135 N., R. 44 W. (15 square miles)	2.8	18.66
T. 134 N., R. 44 W. (30 square miles)	6.7	22.3

BECKER COUNTY

Becker County lies north of Ottertail County and embraces 40 townships, or 1,440 sections. The number of square miles, as estimated by Upham in his report on Becker County for the Geological Survey of Minnesota, is 1,445.41. Upham also estimated the area of lakes in this county to aggregate 137.5 square miles, thus leaving a land area of 1,308 square miles. The swamp land as estimated by the present writer amounts to about 250 square miles.

Becker County includes the continuation of the same series of moraines, till plains, and outwash gravel plains, which have been described in northern Ottertail County. There is a bowlder-strewn till plain in the southeast part. North and west of this are extensive plains of outwash gravel, and beyond these the very rugged sandy moraine, while farther west are gently undulating clayey moraines and till plains. In the midst of the great sandy moraine there is an outwash plain setting in immediately north of the city of Detroit and extending southwestward into northwestern Ottertail County, with a general width of 4 or 5 miles. Its surface is more undulating than the ordinary outwash plains, and lakes of considerable size lie in it or on its border. It contrasts strikingly with the neighboring moraines in its freedom from bowlders, and it also lacks the loam which is generally present on the moraines. A similar gravelly outwash tract is present in the midst of the great sandy moraine in the northern part of the county a few miles east of the White Earth Agency.

The White Earth Indian Reservation occupies twelve townships in the northern part of the county. In this reservation considerable land is cultivated on the till plains and clayey moraine along and west of the Soo Railroad, and a small tract is cultivated on the outwash gravel plain north of Ponsford. With these exceptions the portion of the reservation in Becker County is practically in its wild state.

The western part of Becker County is along the border line between the forest and prairie, and is practically all under cultivation, and the major portion of the land is settled as far east as Richwood, Detroit, and Frazee. There are also old settlements on the outwash gravel plains around Ponsford and Osage, a considerable part of the plain being prairie or covered by a very scrubby timber. The ease of clearing such land compared to that of the heavily forested but richer land to the south accounts for its earlier settlement. Even now there is very sparse settlement of the southeast part of the county, though it is well suited for agriculture. On the rough morainic land east from Richwood farming is scarcely yet begun. There is a belt several miles wide running southward across the county along either side of Ottertail River which seems well suited for grazing land, but much of it is rather broken for farming.

Percentages of Classes of Land in Becker County

	Sq. miles	Per cent of county
Sandy moraine, with sandy to gravelly loam soil...	402	28.2
Clayey moraine, with pebbly clay loam soil........	160	11.1
Outwash gravel and glacial drainage deposits.....	239	16.6

	Sq. miles	Per cent of county
Till plain, with pebbly clay loam soil	253	17.6
Swamp land	247	17.0
Lakes	137	9.5
Totals	1,440	100.0

Farm and Crop Data for Becker County from the Census of 1910

Percentage of land area in farms	41.1
Percentage of farm land improved	50.4
Average acres per farm	171.2
Average improved acres per farm	86.3
Value of all farm property	$11,795,410.00
Percentage of increase since 1900	124.2
Cereals produced in 1909	$976,176.00
Other grains and seeds	$64,545.00
Hay and forage	$300,673.00
Vegetables	$100,164.00
Fruits and nuts	$6,045.00
All other crops	$108,225.00
Total crop value	$1,556,328.00

MAHNOMEN COUNTY

Mahnomen County was organized from a part of Norman County in 1906 and embraces the greater part of the White Earth Indian Reservation, there being sixteen townships or 576 square miles in the county. The western half is almost entirely a clayey till plain and this plain extends a few miles into the eastern half, in the central portion of the county. It is diversified by a few gravelly knolls, and also by a few small lakes. The eastern half is largely morainic, the northeastern portion being a clayey moraine and the southeastern portion more sandy and gravelly. A line of glacial drainage with sandy soil runs along the east border of the northern half of the county, and then leads southwestward past Twin Lakes into northern Becker County.

Percentage of Classes of Land in Mahnomen County

	Sq. miles	Per cent of county
Sandy moraine, with sandy to gravelly loam soil	70	12.2
Clayey moraine, with pebbly clay loam soil	146	25.5
Outwash gravel and sandy glacial drainage deposits	25	4.5

	Sq. miles	Per cent of county
Clayey till plain, with pebbly clay loam soil	309	54.0
Lakes and swamp land	22	3.8
Totals	572	100.0

The western half of the county is largely prairie and contains nearly all the land under cultivation. Fully three fourths of the prairie, however, is in a wild state, though having a very rich soil.

Farm and Crop Data for Mahnomen County from the Census of 1910

Percentage of land area in farms	11.5
Percentage of farm land improved	57.4
Average acres per farm	169.3
Average improved acres per farm	97.3
Total value of farm property	$1,234,111.00
Cereals produced in 1909	$94,707.00
Other grains and seeds	$13,248.00
Hay and forage	$23,793.00
Vegetables	$8,884.00
Fruits and nuts	$9.00
All other crops	$4,994.00
Total crop production in 1909	$145,635.00

NORMAN COUNTY

Norman County, which borders on Red River, has, since Mahnomen County was cut off, an area of 860 square miles. All of this except 125 square miles on the eastern border was covered by the waters of the glacial Lake Agassiz. Nearly half the county has the rich black clay and clay loam of the Red River Valley. On the eastern border, above the limits of the lake, there is a till plain, nearly all prairie, with rich black pebbly clay loam soil. Between the clay belt of the Red River Valley and this till plain is a sandy belt from 8 to 15 miles wide on which occur a number of successive shore lines of Lake Agassiz. These shore lines are narrow ridges of sand or sandy gravel occupying scarcely more than one tenth of the sandy belt. Just below the upper beach there are narrow strips of lake-washed till with sandy to clay loam soil. A few sand dunes occur in the northeast part of the county, and there is some sand on the till beyond the limits of the lake east of Flaming and northward to Fertile in Polk County. In the southeast part of the county outside the limits of Lake Agassiz there are scattered clusters of gravelly knolls rising from 50 to 75 feet above the surrounding till plain. These may mark a temporary ice border and thus be of morainic character.

Percentages of Classes of Land in Norman County

	Sq. miles	Per cent of county
Gravelly glacial knolls	3	0.3
Till plain with sandy patches	14	1.6
Till plain with black pebbly clay loam soil	102	11.9
Lake shores and associated sand	265	30.9
Stony or pebbly sandy loam, lake-washed drift	50	5.8
Black clay and clay loam, lacustrine	405	47.1
Swamp land	21	2.4
Totals	860	100.0

Aside from a part of the sandy land, Norman County has an exceptionally productive soil, and as indicated by the table below, it is very largely under cultivation. Wheat, oats, and barley are raised in large amounts. Farm prices have made some advance since 1910, the average value of a farm with good buildings being now fully $50.00 per acre.

Farm and Crop Data for Norman County from the Census of 1910

Percentage of land area in farms	76
Percentage of farm land improved	75.2
Average acres per farm	253.2
Average improved acres per farm	190.4
Value of all farm property	$16,371,171.00
Average value of a farm	$9,904.00
Cereals produced in 1909	$2,013,945.00
Other grains and seeds	$146,889.00
Hay and forage	$274,104.00
Vegetables	$59,918.00
Fruits and nuts	$3,043.00
All other crops	$37,643.00
Total crop value in 1909	$2,535,542.00

CLAY COUNTY

Clay County, of which Moorhead is the county seat, has an area of 1,043 square miles and extends from Red River eastward a few miles beyond the limits of the glacial Lake Agassiz. The western third of the county has the black clay and clay loam of the Red River Valley; but a narrow water-laid moraine with surface bowlders and looser soil traverses its southern part centrally from north to south. East of the black clay district is a strip of sandy land from 6 to 10 miles wide, in which several successive beaches of Lake Agassiz are present. There is also a water-laid moraine among the beaches and partly covered by lake sand. Barnesville stands on it and it is well developed for several miles north of that village. In the vicinity of Barnesville it is thickly strewn with bowlders, but farther north they are usually covered by lake sand. In the northeastern part of the county, outside the limits of Lake Agassiz, there is a till plain with rich prairie soil of slightly pebbly clay loam. From near Hitterdal southwestward to Muskoda there is a moraine with numerous basins and small lakes among its swells and ridges. From Muskoda it runs southward along the border of Lake Agassiz. It is generally composed of clayey till but includes some gravelly knolls and some sandy land. Outside of this moraine is a strip of gently undulating till with level patches of gravel and sand which follows down Buffalo River to Hawley, but is very narrow farther south. In the southeast part of the county is a prominent moraine which extends into Becker and Ottertail counties. It has a rich prairie soil with pebbly clay loam subsoil. Its surface is rolling, but its slopes are gentle enough for easy cultivation. It includes a number of small lakes, and a small percentage of swampy land.

Percentages of Classes of Land in Clay County

	Sq. miles	Per cent of county
Sandy moraine, with sandy to gravelly loam soil...	10	1.0
Clayey moraine, with pebbly clay loam soil........	157	15.0
Water-laid moraine with variable soil.............	16	1.5
Till plain with pebbly clay loam soil..............	120	11.5
Stony or pebbly sandy loam, lake-washed drift.....	28	2.8
Sandy deposits and old lake shores of pebbly sand..	305	29.2
Black clay and clay loam, lacustrine..............	400	38.4
Swamp land................................	7	0.6
Totals	1,043	100.0

Farm and Crop Data for Clay County from the Census of 1910

Percentage of land area in farms...............	79.6
Percentage of farm land improved.............	82.0
Average acres per farm......................	305.8

Average improved acres per farm	250.8
Value of all farm property	$23,924,607.00
Percentage of increase since 1900	100.4
Cereals produced in 1909	$2,622,637.00
Other grains and seeds	$112,902.00
Hay and forage	$447,917.00
Vegetables	$607,158.00
Fruits and nuts	$3,840.00
All other crops	$21,634.00
Total crop value in 1909	$3,816,088.00

NORTHERN WILKIN COUNTY

An area of 381 square miles in northern Wilkin County, comprising townships 134 to 136 N., ranges 45 to 48 west, is here discussed. It falls within the limits of the glacial Lake Agassiz, except a narrow strip from 1½ to 4 miles wide on the eastern border which rises above the level of that lake. The black clay and clay loam of the Red River Valley extends only 1 to 2 miles east from the river at the southern edge of this district, and about 7 miles at the northern. There is a tract of lake-washed till extending from near the river eastward to the upper beach of Lake Agassiz in T. 134 N., Rs. 45 to 47 W., and the south part of T. 135 N., Rs. 45 to 47 W. Farther north in the northern part of T. 135 N., Rs. 45 to 47 W., and in T. 136 N., Rs. 45 to 47 W., there is a sandy coating over the till, so that it is exposed in only a few narrow strips. Several ridges of sandy gravel, marking the shores of Lake Agassiz, traverse the eastern part of this district, and scattered ridges occur farther west, there being a prominent one from 3 to 6 miles north-northeast of Kent, and less conspicuous ones a few miles farther north.

The water-laid moraine on which Barnesville stands runs southward through the eastern part of T. 136 N., R. 46 W. and has a strong beach developed on its western slope. The part of the district standing above the level of Lake Agassiz consists of a narrow till plain immediately east of the high shore line, and a clayey moraine along the eastern side of the county which extends into Ottertail County.

With the exception of a few small brushy areas along the streams this is a prairie region and the clayey portion has a rich black soil. The sandy portions vary considerably in fertility. A few square miles in T. 135 and 136 N., R. 47 W. have a light sand which is subject to drifting by the wind. The old shore lines are composed of a sandy gravel with rather light soil, but sandy tracts among them have an admixture of loam, and also have less depth to the water table, so that they are moderately productive.

Percentages of Classes of Land in Northern Wilkin County

	Sq. miles	Per cent of district
Clayey moraine, with pebbly clay loam soil	22	5.8
Till plain, with pebbly clay loam soil	28	7.4
Stony or pebbly sandy loam, lake-washed drift	102	26.7
Pebbly clay loam, lake-washed drift	58	15.2
Sandy desposits of Lake Agassiz	91	23.9
Black clay and clay loam, lacustrine	70	18.4
Swamp land	10	2.6
Totals	381	100.0

The extent of cultivation of the land in Wilkin County is about the same as in northern Clay County, and there is a similar land value and crop production.

INDEX

Page
Acknowledgments 2, 3, 5
Agassiz, Lake 36
Agricultural conditions 7, 28
Agriculture, relation to geology 1
Altitudes in Minnesota 7
America 46
Annual temperatures 12
Anticyclone 10, 11
Bagley 56
Barnard, E. C., acknowledgments to 58
Barnesville 73
Becker County 68
Beltrami County 57
Beltrami Island 58
Bemidji 57
Big Sioux River, rainfall on 25
Black Duck 60
Breadth of Minnesota 10
Bronson 44
Bureau of Soils 50, 53
Bureau of Soils, acknowledgments to 2, 6
Butters, Fred K., acknowledgments to 39
Caribou 43
Carmel 59
Cass County, part of 62
Chamberlin, R. T., work of 6
Clay County 72
Clear River 46
Clearwater County 55
Climate of Minnesota 10, 11
Cold waves 11
County reports 43, 75
Crookston 53
Crop-growing season 13, 21
Crow Wing County, part of 62
Cyclones 10, 11
Damaging temperatures 18
Department of Agriculture, acknowledgments to 2, 6
Des Moines River rainfall 23
Detroit 69
Drainage of Minnesota 8
Drift, general features 7
Drift, maps showing 32
Driftless area 38
Duxby 46
Earthy mantle 30
Elftman, A. H., work of 2
Emmons, W. H., introduction by 1
Falun 46
Faris 64
Fertile 71
Field work 5
First killing frost 19
Flaming 71
Forests 38

Page
Frazee 69
Frosts 18
Frosts, Lake Superior shore 18
Funkley 60
Garden Island 59
Geological and Natural History Survey 6
Glacial deposits 32
Glacial features 35
Glacial lakes 36
Greenbush 45, 46
Growing season 13, 21
Hackensack 63
Halma 44
Hawley 73
Hemmington 43
Highest temperatures 16
Hitterdal 73
Hubbard County 64
Humidity 26
Island Lake 61
Itasca County, northwestern part of 61
Jelle 59
Johnston, W. A., acknowledgments to 58
Kelliher 60
Killing frosts, dates of 19, 20
King 47
Kittson County 43
Koochiching County, western part of 60
Lakes 9
Lakes, number of 11
Lake Agassiz 7
Lake beaches 37
Lake deposits 32
Lake Duluth 37
Lake Itasca 55
Lake Superior, frosts on 18
Lake Superior rainfall 23
Land classification 42
Last killing frost 20
Leaf River 65
Length of Minnesota 10
Lime 40
Limestone 41
Loess 31
Longville 63
Louis 60
Lowest temperature 17
McDole, G. R., work of 2
McDonnell, A. R., acknowledgments to 58
McMiller, P. R., work of 2
Mahnomen County 70
Malcolm 59
Manitou Rapids 60
Mantle rock 30
Map (in cover), use of 3
Marl 41

Page
Marshall County 47
Meade, A. P., acknowledgments to....... 55
Mean annual temperatures.............. 13
Mesabi Iron Range, elevation of......... 8
Mille Lacs 9
Minnesota national forest................ 61
Minnesota, rainfall 23
Minnesota, topography 7
Mississippi River, rainfall................ 23
Mississippi River, sand on............... 31
Monthly temperatures 24
Moorhead 72
Moraines 67
Mud Lake 47
Muskoda 73
Norden 61
Norman County 70
Orheim 59
Orleans 43
Orth 61
Osage 69
Ottertail County, northern part of........ 66
Park Rapids 64
Park region 66
Pennington County 48
Perham 67
Pelan 43
Pine Creek 46
Pine Lake 67
Plant food 40
Polk County 53
Ponsford 69
Popple 61
Posey, C. J., work of.................. 2
Prairies 39
Precipitation 22, 24
Preston, Earl R......................... 6
Purssell, U. G., acknowledgments to...... 2
  chapter on Climate by.............10-29
Rainfall 22, 23, 24, 42
Rainy days, number of.................. 27
Rainy River 60
Rainy River, rainfall.................. 23
Ralph, George A., estimates by......... 65
Red Lake 9, 59
Red Lake County...................... 51
Red Lake Falls........................ 52
Red Lake Indian reservation...........55, 56
Red River Valley...................... 34
Relief of Minnesota.................... 8
Reservations 55
Residuary material 31
Richwood 69

Page
Rock outcrops 30, 58
Roseau County 45, 46
Ross 46
St. Paul, rainfall at..................... 25
Sand 31
Sand Hill River........................ 54
Sardeson, F. W., work of.............. 2
Sawtooth Range 8
Scope of paper......................... 5
Season 21
Seasonal temperatures 18
Shevlin 56
Smith, W. G., statement by............50-51
Snowfall 26
Soils, general conditions................ 38
State reservations 55
Storms 11
Stream deposits 32
Sunshine, amount of.................... 27
Swift 46
Temperatures 11, 12
  in January 14
  in July 15
  highest 16
  lowest 17
  monthly 24
Thief River 48
Thief River Falls........................ 48
Thorhult 59
Topographic maps, cost of.............. 67
United States Bureau of Soils, acknowledgments to 2, 6
United States Geological Survey, coöperation with 2
United States Weather Bureau, acknowledgments to 2
  work of 11
Upham, Warren, acknowledgments to.....6, 39
Vegetation 38
Wadena County 65
Wannaska 46
Warroad 46
Water falls 9
Wayland 61
Weather Bureau, acknowledgments to.... 2
  work of 11
Weathering 40
White Earth Indian Reservation........55, 69
Width of Minnesota.................... 10
Wilkin County, northern part of......... 74
Winchell, N. H., acknowledgments to.... 2
Wind deposits 31
Winds 11, 26

The University of Minnesota

MINNESOTA GEOLOGICAL SURVEY

WILLIAM H. EMMONS, DIRECTOR

IN COÖPERATION WITH THE UNITED STATES GEOLOGICAL SURVEY

BULLETIN NO. 13

SURFACE FORMATIONS AND AGRICULTURAL CONDITIONS OF NORTHEASTERN MINNESOTA

BY

FRANK LEVERETT

AND

FREDERICK W. SARDESON

WITH A CHAPTER ON

CLIMATIC CONDITIONS OF MINNESOTA

BY

U. G. PURSSELL

MINNEAPOLIS
The University of Minnesota
1917

CONTENTS

Introduction 1-4

Field work and acknowledgments 5

Chapter I. Physical features of Minnesota 6-23
- Topography of Minnesota 6-11
  - General statement 6
  - Altitude 7
  - Relief 7
  - Drainage 10
  - Lakes 11
- Surface geology 11-19
  - Rock areas 11
  - The earthy mantle 12
    - General statement 12
    - Residuary material 12
    - Wind deposits 12
      - Loess 12
      - Wind-blown sand 13
    - Glacial deposits 13
    - Stream deposits 15
    - Lake deposits 15
  - The glacial features and their history 16
  - Glacial lake features 17
- General soil conditions 19-23
  - Vegetation 20
  - Weathering 20
  - Lime 22
  - Effects of fires 22

Chapter II. Climatic conditions of Minnesota 24-44
- Introduction 24
- General climatic conditions 25
  - Temperature 25
  - Frosts 32
  - Precipitation 37
  - Snowfall 40
  - Winds 40
  - Relative humidity 40
  - Number of rainy days 41
  - Sunshine 41
  - Tables showing winds and humidity 42-43

Chapter III. Agricultural conditions and land classification...... 45-67
  General statement 45-49
  Descriptions of counties.................................. 49-67
    Cook County 49
    Lake County 51
    St. Louis County.................................. 55
    Koochiching County 58
    Itasca County 61
    Eastern Cass County.................................. 63
    Northeastern Crow Wing County.................................. 63
    Aitkin County 64
    Carlton County 67

LIST OF ILLUSTRATIONS

Plate I. Map of surface formations of Minnesota (Sheet II) ....in pocket

II. A. Superior red drift over Patrician red drift near Cloquet

B. Clayey Keewatin drift over stony Patrician drift at Biwabik 12

III. A. Gravel Outwash in Lake County

B. Gravel in beach of Lake Agassiz............... 16

IV. A. Esker between lakes in eastern Lake County

B. Interior structure of an esker in Lake County... 18

V. A. Garden plot of Anthony Gasco on Lake Harriet, Lake County

B. Farm on shore of Lake Superior at Lutzen, Cook County 46

VI. A. Shores and islands of Vermilion Lake

B. Cross River meandering through a spruce swamp in its headwaters.......................... 48

VII. A. Field of oats on Keewatin till plain in St. Louis County

B. Dairy farm, St. Louis County................. 50

VIII. A. Breaking ground at Meadowlands

B. Stock farm at Meadowlands

C. Farm premises at Meadowlands............... 52

IX. A. Fertile valley north of Vermilion Lake at "Half-Way House"

B. Farm on the stony Patrician drift at Tower..... 54

X. A. Farm on clayey Keewatin drift east of Cook

B. Pioneer marketing at Cook.................... 56

XI. A. Clearing in poplar forest on Little Fork River, St. Louis County

B. Ditching a muskeg in St. Louis County

C. Jack pine over 100 feet high at Sturgeon Lake, St. Louis County.......................... 58

XII. A. First crop on land stumped the previous year at Experiment Farm, Duluth

B. Heavy steel disk used in preparing new soil

C. Winter view at Duluth Experiment Farm....... 60

Plate XIII. A. Corn with good sized maturing ear, at Duluth Experiment Farm
B. Corn suitable for ensilage at Duluth Experiment Farm 62
XIV. A. Spruce and poplar on bed of Lake Agassiz west of Cook
B. Muskeg in bed of Lake Agassiz near Big Falls.. 64
XV. A. Very bowldery land on Mesabi Range near Hibbing
B. Rocky areas in northeastern Minnesota......... 66

TEXT FIGURES

Fig. 1. Altitude map of Minnesota............................ 8
2. Map showing glacial drifts, loess, and glacial lakes in Minnesota 14
3. Map of Minnesota showing distribution of forest and prairie 21
4. Map showing mean annual temperatures of Minnesota (degrees Fahrenheit) 26
5. Map showing mean temperatures of Minnesota for January (degrees Fahrenheit) 28
6. Map showing mean temperatures of Minnesota for July (degrees Fahrenheit) 29
7. Map showing highest known temperatures in Minnesota (degrees Fahrenheit) 30
8. Map showing lowest known temperatures in Minnesota (degrees Fahrenheit) 31
9. Map showing average date of the last killing frost in spring in Minnesota 33
10. Map showing average date of first killing frost in autumn in Minnesota 34
11. Map showing number of days of the average crop-growing season in Minnesota............................ 35
12. Map showing the average annual precipitation for Minnesota 36
13. Diagram showing comparative monthly distribution of precipitation in Minnesota............................ 38
14. Diagram showing mean monthly rainfall and mean monthly temperature at several stations in Minnesota......... 38
15. Diagram showing rainfall and temperatures (degrees Fahrenheit) at St. Paul, Minnesota, from 1837-1913.. 39

INTRODUCTION

BY W. H. EMMONS

Soil is the loose unconsolidated material which nearly everywhere covers the surface of the earth and in which plant life may be maintained. It is made up of finely divided rock in which decaying vegetable matter and animal matter are mingled. A soil is generally in a state of change. It is being washed little by little to the creeks and rivers which carry it to the sea, where it often forms delta deposits; if no new soil formed, hard rock would finally be exposed instead of the loose plant-producing soil. But rocks at and near the surface are continually changing and new soil is being formed from the underlying rock or from loose clayey or gravelly material that may constitute the subsoil, or from bowldery material that at many places in Minnesota lies between the hard rock and the soil.

Water and air attack rock matter and break it down. Heat and cold, freezing and thawing, shatter the rocks and give plants an opportunity to send roots into the cracks that are formed, and these, prying the rocks apart, reduce them to particles of still smaller size. Even the hard, solid rocks are ultimately broken down; a building of good solid stone may crumble in a few hundred years, particularly in a moist climate.

Some of the rocky matter is dissolved by the water and carried to the sea in solution. It is such dissolved material that makes water "hard" and that gathers in the bottom of a vessel when water is boiled. But not all of the soluble substances are dissolved and carried away; some remain in the soil and the character of the soil depends largely upon these. Some soils are acid because they have not enough lime. Some are deficient in potash or phosphates, which are necessary if soil is to produce certain crops satisfactorily.

Because it forms the soil, the composition of the underlying material is of great importance. In Minnesota most of the soil is the weathered portion of glacial drift or of lake beds and other features connected with the deposition of the drift. Long ago nearly all of what is now the state of Minnesota was covered over with a great ice sheet hundreds of feet thick that slowly moved down from the Canadian highland carrying with it rocky material which it had gathered in the north. When the ice melted it left large quantities of rock and soil that had mingled with the ice and this material is the loose drift that lies between the hard rock and the surface. At many places where it is not yet disintegrated it appears as large groups of bowlders mixed with clay. Although the ice sheet moved very slowly, perhaps not more than a few rods a year or even less, it was active for a long period and locally it scoured the country clean of soil and loose material which on melting it piled up somewhere else.

This statement of the origin of the loose material or drift is not speculation, but is substantiated by the most convincing facts. The deposits and all of the features of the country formerly covered with ice are like those that may now be observed in Greenland or Antarctica, where the slowly moving ice fields or glaciers still cover bodies of land of continental proportions. Glacial bowlders, bowlder clay, scratches on the rocks, morainal hills and kettles, all ordered with respect to definite features of the former ice sheet, may be seen at thousands of places in Minnesota.

In the northern parts of Cook, Lake, and St. Louis counties the ice sheet removed the soil and subsoil, laying bare the underlying hard rock. Before the ice melted in this region it had carried the loose material away. Since that time there has been some weathering of the rock, but at most places not enough to give a good workable soil. Many of these areas are in the Superior National Forest and are well suited for growing forests although they have little or no value for farming. In the southern parts of these counties near the lake there are areas with loose sandy soil well suited to growing garden truck.

The last great ice sheet that covered the area melted very slowly and the southern part was melted long before the northern part. The ice that still remained in the north formed a great dam which held back the drainage of the Red River basin and formed a large lake which is called the glacial Lake Agassiz. This extended from the Red River Valley and plains of Manitoba as far east as the western part of the area herein described, covering nearly all of Koochiching County and the northwestern part of St. Louis County. When the ice retreated and this lake was drained, there were left the old beach ridges which now supply building sites and road material. Extensive beds of lake sediments were left also, and when these are suitably drained they make good soil. Other lakes smaller than Lake Agassiz, but yet extensive, were formed also. When they were drained, their beds likewise became available for plant growth and where properly drained they generally make good soil, especially where the soil contains sufficient clay.

Swamps are very numerous in the northeast quarter of the state. They are portions of the old lake beds and other poorly drained areas and are of little value for agriculture until drained. Since the ice melted a growth of vegetation has been established on them and great thicknesses of partially decayed vegetation have accumulated in them. This forms the peat which is found in so many of the swamps. Some of it is very thick and will doubtless become a valuable asset in the future when other fuels shall have become more costly.

The great productivity of Minnesota soils is due, not only to their recent origin by reason of which nearly all of them still contain the soluble mineral foods for plants, but also to a favorable climate. The low temperatures which frequently prevail during certain periods in winter make for healthful conditions for animal life and they also benefit plant life. The rainfall, though not excessively great, is sufficient and, since most of it occurs during the growing period, drouths are rare and crop failures almost unknown except in the more sandy soils, which are, however, adapted to quick-growing crops like potatoes. As shown herein, the length of the crop-growing season, that is, the time between late spring frosts and early autumn frosts, is between 100 and 170 days for all except the extreme northeast corner of the state. The long days, high proportion of sunshine, and the moderate humidity are all favorable to plant growth.

This bulletin is a preliminary paper which treats the soils of only the northeast quarter of Minnesota. It will be followed by a report on the entire state, the field work for which already has been completed. The work has been done in accordance with the agreement for coöperation between the United States Geological Survey and the Minnesota Geological Survey, entered into, March, 1912. By this agreement the services of Mr. Frank Leverett were secured for surveying the surface formations and soils. Mr. Leverett has been engaged since 1886, or thirty years, in studying the surface geology of the Great Lakes region and because of his large experience in the greater area he was particularly well prepared to undertake the studies in Minnesota. He has spent, moreover, considerable time in the state studying its physiography in connection with the preparation of a monograph for the United States Geological Survey. Since the reorganization of the State Survey, the salary of Mr. Leverett has been met by the United States Geological Survey, while the greater part of his expenses have been paid by the State Survey. The State Survey has provided also for this work the services and expenses of Professor F. W. Sardeson, who has assisted in this work for the past five seasons. For a short period, also, the State has supplied the services of Dr. Arthur H. Elftman. We wish to acknowledge the generous assistance of the Division of Soils of the Department of Agriculture of the University of Minnesota and of the United States Bureau of Soils. The valuable contributions to the knowledge of the surface formations of Minnesota by the Minnesota Geological and Natural History Survey, under the direction of Professor N. H. Winchell, particularly those of Mr. Warren Upham of that Survey, have aided greatly in the preparation of this report. The section on climatic conditions in Minnesota has been generously contributed without any cost to the Survey by Mr. U. G. Purssell, Director of the Minnesota Section of the United States Weather Bureau. In the preparation of the maps and other data showing dates of killing frosts, lengths of growing season, rainfall, etc., Professor C. J. Posey has rendered efficient service.

The cost of preparation of this report has been met by the Minnesota Geological Survey and the United States Geological Survey. This bulletin is printed by the Minnesota Geological Survey. Arrangements have been made so that land and colonization companies can secure these reports at actual cost of printing, and it is expected that this arrangement will secure a wide distribution. The maps are not intended to be used as a basis for the purchase of land; they do not give an accurate description of each forty-acre tract or each section, but they show the general classification of the land, its climate, and its surroundings.

SURFACE FORMATIONS AND AGRICULTURAL CONDITIONS IN NORTHEASTERN MINNESOTA

By Frank Leverett and Frederick W. Sardeson

FIELD WORK AND ACKNOWLEDGEMENTS

The field embraced in this report on northeastern Minnesota includes the whole of Cook, Lake, and St. Louis counties, and parts of Koochiching, Itasca, Cass, Crow Wing, Aitkin, and Carlton counties. Its southern limit is the median line of the state, which is near latitude 46° 25′, and its western line is the 94th meridian. It embraces about 17,280 square miles, a little more than 20 per cent of the state.

Following the plan in *Bulletin No. 12,* on Northwestern Minnesota, a brief general description of the surface features and deposits of the entire state is given, and the climate of the entire state also is discussed.

In addition to the field work by the authors, assistance was rendered by Earl R. Preston for two months in studies in Cook, Lake, and St. Louis counties. In the study of these counties assistance was also rendered by Dr. Arthur H. Elftman for a brief period. Dr. Elftman had, some years previously, explored a considerable part of Lake and Cook counties as a member of the Geological Survey under Professor N. H. Winchell, and was thus able to supply valuable data in reference to parts of the county which now are not easily accessible, because of the lack of roads or trails, and which were then studied by working out from camps and by canoe trips through the lakes and connecting streams. In the preparation of this report much aid has been derived from the publications of the Geological and Natural History Survey of Minnesota, prepared under the direction of Professor N. H. Winchell. Much use has been made also of the volume by George A. Ralph, State Drainage Engineer, entitled *Topographical and Drainage Survey of Minnesota for 1906.* Its maps have been especially valuable as a basis for estimating the swamp land areas, and its lines of levels for drawing the contours which appear on Plate I of the present report. Aid has been rendered also by numerous residents of the region in supplying information and in guidance through parts difficult of access, a kind of assistance which is especially valuable in a region so sparsely inhabited and imperfectly opened to travel.

CHAPTER I

PHYSICAL FEATURES OF MINNESOTA

TOPOGRAPHY OF MINNESOTA

GENERAL STATEMENT

The position of Minnesota is near the center of the North American Continent, and the state embraces an area of 84,682 square miles, of which about 93 per cent is land and 7 per cent water. Its extreme length is nearly 400 miles, from latitude 43° 30′, at the Iowa line, to a point about 23 miles north of the 49th parallel, in the projection known as the Northwest Angle, northwest of Lake of the Woods. The greatest width is 367 miles, but the average width is only about 225 miles, or but little more than half of the length.

Minnesota presents more variety in surface features than most of the north central states, yet a great part of its surface is level or only gently undulating. The flattest portion falls largely in the northwest quarter, and was once the bed of the glacial Lake Agassiz, a lake held in on the north, in central Canada, by the great ice sheet. The roughest portion is in the northeastern quarter within the area embraced in this report. This part is composed largely of volcanic formations and iron-bearing rocks which, though glaciated, were not everywhere buried beneath the glacial deposits. In the southeastern part of the state deep erosion valleys along the Mississippi and its tributaries present bold rock bluffs 300 to 600 feet high. The interior and southern parts of the state have features due almost entirely to the work of the great ice sheets, which at successive times, and from different directions, overspread Minnesota. The glacial deposits comprise an intricate system of moraines with undulating to hilly surface, associated with which are level outwash plains of sand and gravel, and gently undulating intermorainic till plains. The moraines were formed along the border of the ice at definite lines where the edge of the ice held its position for a relatively long time. They consist of sharp knolls and inclosed basins and also of more or less parallel ridges which, however, interlock in places. These moraines are distributed in rudely concentric systems which mark successive positions of the border of each ice sheet as it was melting off from this region. The outwash plains lie on the outer border of the moraines, where sandy gravel was spread out by dirt-laden waters escaping from the ice. The till plains lie along the inner or iceward border of the moraines and represent areas over which the ice border melted back somewhat rapidly, forming relatively few knolls and ridges.

ALTITUDE

The altitude of Minnesota ranges from 602 feet, the level of Lake Superior, up to 2,230 feet, on high rock hills in the northeast part of the state, in western Cook County. The small map, Figure 1, shows that a large part of the state falls between 1,000 and 1,500 feet. The average altitude of the state is not far from 1,200 feet. The portions above 1,500 feet lie chiefly in two areas, one at the northeast and one at the southwest corner of the state, though there is a good sized area around the sources of the Mississippi River in the western part, and several smaller areas in that vicinity; one of these in the southern part of Otter Tail County is known as the Leaf Hills. The altitude of the elevated area in the southwestern part falls short a little of reaching 2,000 feet, but that in the northeastern part includes several small areas, chiefly in Cook County, that rise above 2,000 feet. The portions below 1,000 feet fall in two areas widely separated except for a connecting line along the Minnesota valley, one being on the western edge of the state and the other on the eastern. There is also a narrow strip bordering Lake Superior. The 100-foot contours which appear on the glacial and soil map of northeastern Minnesota (Plate I), show the altitude relations in the district embraced in the present report, while Figure 1 sets forth the conditions for the remainder of the state.

RELIEF

The most conspicuous relief is found in the "Sawtooth Range" and other prominent ridges that closely border Lake Superior and which rise abruptly from 500 to 900 feet above the lake. The rock ranges lying back from the shore, though more elevated than those fronting on the lake, seldom rise more than from 200 to 300 feet above the swamps and lakes among them. In fact several of the lakes of Cook County are above 1,900 feet or within 300 feet of the level of the highest points in the state. The most prominent part of the Mesabi Iron Range in St. Louis County rises from 400 to 450 feet above bordering plains. The Coteau des Prairies rises about 700 feet above the plain northeast of its border, but in Minnesota the rise is usually spread over a space of from 12 to 15 miles or more in width, so that the elevation can scarcely be appreciated by one crossing over it. There is a rather rapid rise of from 300 to 500 feet to the sharp range of hills in Otter Tail and Becker counties from the Red River valley. This rise is of especial interest since it seems to have some influence on the rainfall, the precipitation being greater in these hills where air currents are forced upward and cooled than in the bordering lower lands to the north, west, and south.

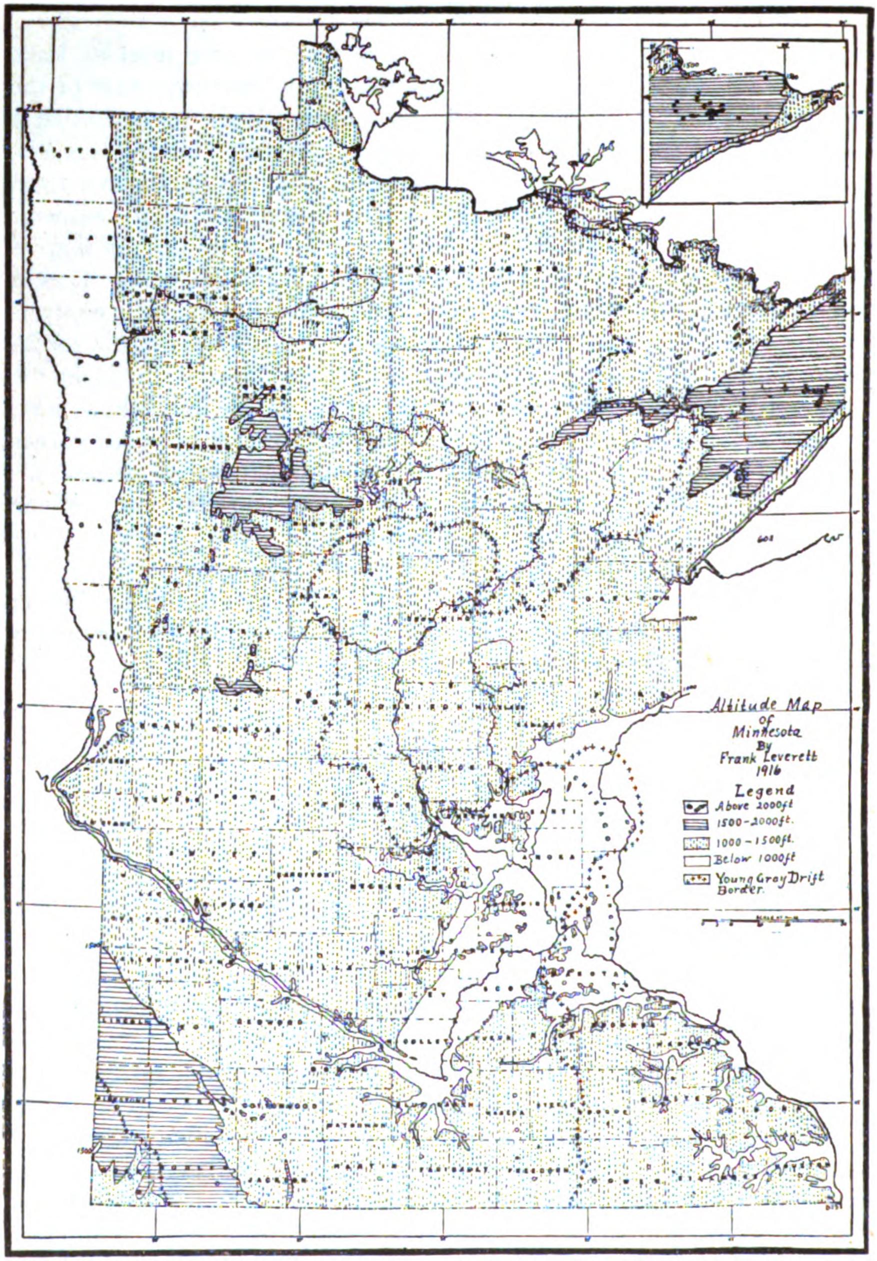


FIGURE I. ALTITUDE MAP OF MINNESOTA

EXPLANATORY NOTE, FIGURE 1

This map shows the great extent of land in Minnesota standing between 1,000 and 1,500 feet above sea level, as well as the distribution of the higher areas and of areas standing below 1,000 feet.

It shows also the effect of low areas in favoring the movement of the latest invasion of ice from the north, that which deposited the young gray Keewatin drift, as well as the effect of the high areas in checking the movement. The great axial movement of the ice was through the low-lying Red River basin, much of which is below 1,000 feet, and thence down the Minnesota valley to the great bend at Mankato over a plain much of which is below 1,100 feet. The thumb-like offshoot of the ice, in a lobe extending from Wright and Hennepin counties northeastward across Anoka, Isanti, and Chisago counties, into the edge of Wisconsin, was apparently induced by an exceptionally low area, largely below 1,000 feet, over which it passed. In northern Minnesota the ice passed over the relatively low land, 1,200 to 1,300 feet, along and near the Mississippi River in Cass and Itasca counties, into the St. Louis River basin in St. Louis County, and down the Mississippi in Aitkin County; but it was so checked by higher land, 1,500 to 1,750 feet, in Clearwater, Becker, and Hubbard counties, that it could there reach only southeastern Hubbard and neighboring parts of Cass and Wadena counties. The Mesabi Range also held the ice border back nearly to the western edge of St. Louis County while it pushed eastward some distance in St. Louis County, both north and south of the range.

The topography also influenced ice movement in the northeast part of the state. There was a strong movement of ice southwestward through the Superior basin, with its northwest border only a few miles back from the shore on the high land, much of which stands 1,500 feet or more above the sea. This high land was largely covered by a southward ice movement from still higher land in the neighboring part of Canada. The relations of this ice movement to that in the Superior basin, as well as to that which covered western Minnesota is set forth in the discussion of the glacial deposits.

DRAINAGE

The drainage of Minnesota is widely divergent, part of it leading to the Gulf of Mexico, part to the Gulf of St. Lawrence, and part to Hudson Bay. The Gulf of Mexico receives about 57 per cent, the St. Lawrence less than 9 per cent, and Hudson Bay fully 34 per cent of the drainage. There was a time, however, after the glacial ice had melted from Minnesota but was still occupying the northeast part of the Superior basin and neighboring parts of Ontario and Manitoba, when all the drainage was southward to the Gulf of Mexico. The western Superior basin then overflowed into the St. Croix River, while the Red River drainage basin, largely covered by Lake Agassiz, drained southward through Lakes Traverse and Bigstone into the Minnesota valley.

The drainage to the south, or Gulf of Mexico, has generally a gentle descent, and waterfalls are rather rare, though the Mississippi has notable falls at Minneapolis and there are one or more falls or rapids on several of the tributaries. The drainage to Lake Superior is generally rapid and nearly every stream has several cascades. There is, however, a wide area of the upper St. Louis basin in which that stream and its tributaries have relatively gentle descent for many miles. The Hudson Bay drainage has a few rapids and waterfalls in the headwater part of Rainy River and its tributaries, but Red River and its main Minnesota affluent, Red Lake River, have no falls since no outcrops of solid rock occur along them. There is, however, very rapid descent for a few miles along Red Lake River and its tributary Clearwater River in Red Lake County. Red River is subject to great freshets because its lower course often remains frozen after the southern or headwater part has broken up. Thus ice jams are formed which divert the waters from the channel over the bordering plain.

Of the 17,280 square miles of the area embraced in the present report, 5,550 square miles drain to Lake Superior, 8,042 square miles to Rainy River of the Hudson Bay drainage system, and 3,688 square miles to the Mississippi River and tributaries. The streams of these several drainage systems are interwoven in the western part of the area, there being no prominent dividing ridges to separate them. In some cases a swamp may be drained either to the Hudson Bay or to the Gulf of Mexico system, while other swamps may be drained either to the Mississippi system or to Lake Superior. In the northeastern part of the area there is less interweaving of the drainage, though even there easy canoe portages are made between the Hudson Bay drainage and the drainage to Lake Superior.

LAKES

Throughout much of Minnesota, except the northwest, southwest, and southeast corners, small lakes are a common feature. They usually occupy basins among the moraine ridges and knolls and on the outwash plains, but occur to some extent also on the till plains and among rock knobs. The combined area of the lakes within the state is estimated to be about 5,650 square miles, or nearly 7 per cent of the entire area. The largest lake is Red Lake, a very shallow body of water with an area of 440 square miles. Other large lakes are Mille Lacs, also very shallow, Leech, Winnibigoshish, and Minnetonka. Minnetonka and the southern part of Leech Lake extend into a network of deep depressions among morainic ridges, but the other lakes are largely in plains that are slightly below the neighboring districts, partly morainic and partly plain.

SURFACE GEOLOGY

ROCK AREAS

The areas in which rock is so exposed as to render the land untillable are largely in the northeast quarter of the state, or along valleys in the southeast quarter. The northwest quarter is estimated to have less than 10 square miles of bare rock outcrop, and the southwest scarcely 100 square miles. It is doubtful if there is an area of 1,000 square miles in the entire state in which the plow would generally strike into rock ledges. The rock areas thus form a much smaller percentage of the state than the lake areas. The rock areas of the northeast part are chiefly rock bosses standing above the surrounding land, but the beds of the streams that lead directly down to Lake Superior are also usually on rock ledges. Among the rock knobs are some depressions covered only with moss and peaty material, glacial material being scanty, but ordinarily some glacial material is present and nearly all the land has soil enough over the bedrock to support a rich forest growth. Many of the knobs preserve the smooth surface left by the scouring effect of the ice sheet and are nearly destitute of vegetation. But certain others have become disintegrated to a depth of several inches or even to several feet from the surface and are supporting growths of vegetation of considerable density.

The rock areas of the southwest part of the state are largely of Sioux quartzite which in places comes to the surface over areas of several square miles. The rocks have scarcely enough soil over them to support the scanty vegetation. There are a few small areas of granite knobs along the Minnesota Valley from Bigstone Lake down to New Ulm. In the driftless area and part of the drift-covered area in southeastern Minnesota, rock ledges of limestone and sandstone outcrop along the steep slopes of the valleys, often forming walls of considerable height. Rock is rarely exposed along the stream beds and valley bottoms. The uplands and the higher parts of the slopes of the valleys even in the driftless area usually have several feet of residuary clay and also a coating of loess or wind-deposited silt loam covering the rock formations and rendering the land tillable.

THE EARTHY MANTLE

GENERAL STATEMENT

The variety of earthy, sandy, and gravelly unconsolidated deposits which cover the rocky floor of Minnesota were formed or deposited by different agencies and at different times. They may be grouped as follows:

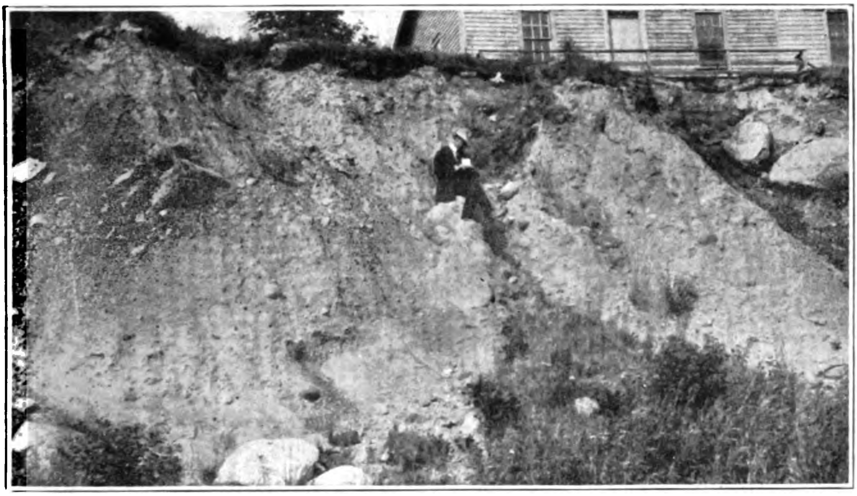
First. Residuary material.
Second. Wind deposits.
Third. Glacial deposits.
Fourth. Stream deposits.
Fifth. Lake deposits.

RESIDUARY MATERIAL

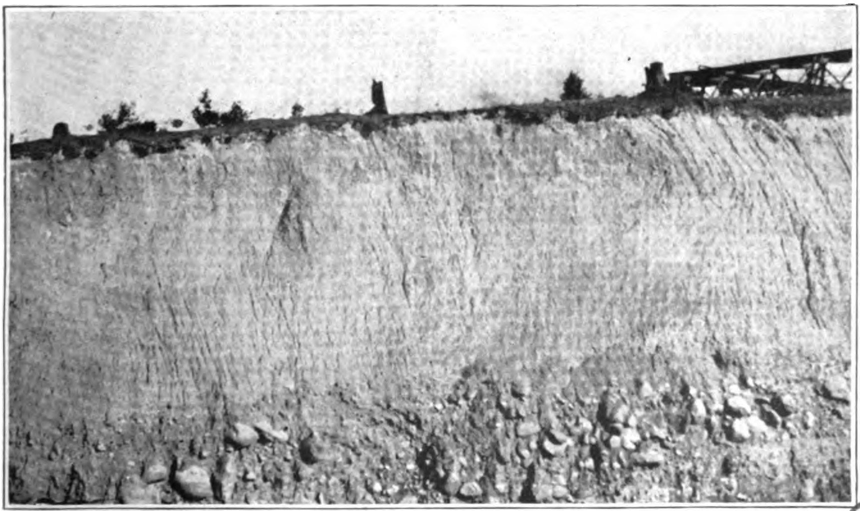
The residuary material, as its name implies, has been left as a residue during the breaking down or decay of the surface rocks through weathering and solution. On limestones it is usually a dark, reddish brown, gummy clay, but on sandstones and crystalline rocks it is usually granular and loose-textured. There is but a small part of Minnesota, chiefly in the southeastern counties, where residuary material is within reach of the plow. It occurs there on the upper part of the slopes of the valleys and on the narrow upland strips between valleys, but it is usually covered by loess.

WIND DEPOSITS

Loess.—The wind-deposited material known as loess is largely a fine silt loam, which forms the surface in an area in the southeast part of the state embracing much of Goodhue, Olmsted, Wabasha, Winona, Fillmore, and Houston counties and parts of Mower, Dodge, Rice, and Dakota counties. It covers a small tract in the southwest part of the state in Rock, southern Pipestone, and western Nobles counties. In the southeastern counties it rests in part on glacial drift deposits and in part on the residuary clay and rock formations of the driftless area. In the southwestern part it covers glacial deposits. In the southeast district its border is very irregular, there being long strips of loess-covered land projecting westward or northwestward into the region free from loess, and



A. SUPERIOR RED DRIFT OVER PATRICIAN RED DRIFT NEAR CLOQUET. THE MAN SITS ON A BOULDER AT THEIR JUNCTION



B. CLAYEY KEEWATIN DRIFT OVER STONY PATRICIAN DRIFT AT BIWABIK

UNIV. OF MICH.

also long strips free from loess extending eastward into the loess-covered tracts. The condition there is such as might result from the presence or absence of vegetation giving different degrees of protective power from the wind; areas with dense vegetation being able to hold dust that settled from the atmosphere while bare ones allowed it to be gathered up and carried on.

Wind-blown sand.—Wind-blown sand is also an important deposit. It embraces a district east of the Mississippi from Minneapolis up to Brainerd. It is narrow above St. Cloud, but below that city extends eastward to the St. Croix River. The sand does not, however, cover the entire surface in this area. Where present it rests upon glacial deposits. It has low ridges seldom 20 feet and usually 10 feet or less in height. There is more or less wind-drifted sand in the sandy parts of the St. Louis River drainage basin, but it is sparingly developed compared to that in the district between the Mississippi and St. Croix rivers. Wind-blown sand occurs also in Aitkin County in the vicinity of McGregor and also in the northeastern part of the county in island-like tracts that are surrounded by marshes. There are numerous small areas of such sand scattered over the state, some of them being along the shores of the glacial Lake Agassiz.

GLACIAL DEPOSITS

The glacial deposits as shown in Figure 2 extend over the entire state except eastern Winona County and the greater part of Houston County, which are in the driftless area of the upper Mississippi. They underlie the wind-deposited sands and much of the loess area. They also underlie stream deposits and lake sediments. The glacial deposits are separable into till or bowlder clay in which stones, clay, and sand are closely commingled; and into sand or gravel beds which show some assorting and bedding by water action. The percentage of stony material varies greatly and the matrix also shows variations from compact clay to loose sand. These variations are to be expected in a deposit that had been formed from the dirt and stones included in an ice sheet. Every observing farmer has probably noted and perhaps speculated upon the cause for these variations in the drift deposits which form the basis for so large a part of the Minnesota soil. The assorted sand and gravel beds are largely due to waters escaping from the melting ice and many of them may be traced up to a moraine which marked the position of the ice border at the time they were laid down. They show a decrease in coarseness in passing away from the edge of the moraine, the coarse material having been dropped close to the edge of the ice and only the fine carried to a great distance outside.

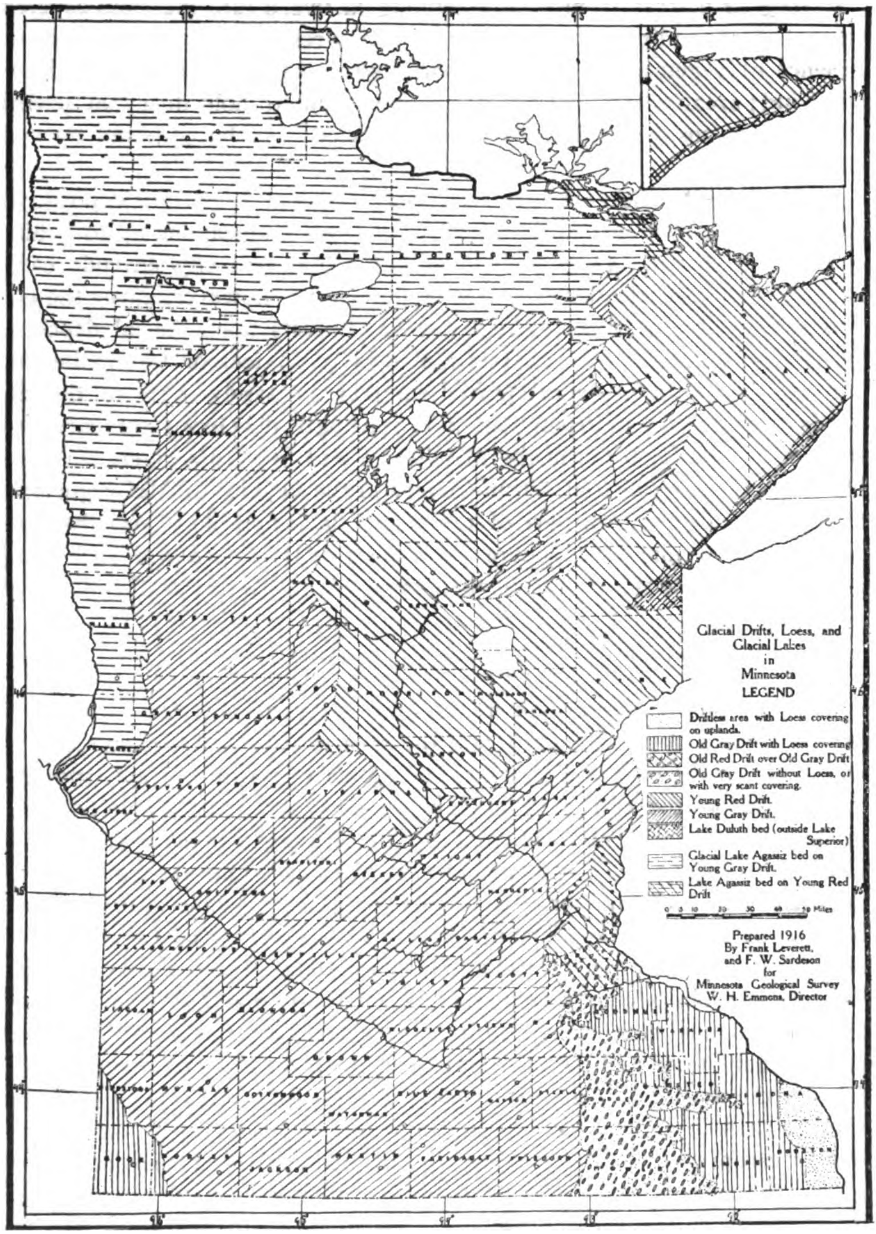

Glacial Drifts, Loess, and Glacial Lakes in Minnesota
LEGEND
Driftless area with Loess covering on uplands.
Old Gray Drift with Loess covering
Old Red Drift over Old Gray Drift
Old Gray Drift without Loess, or with very scant covering.
Young Red Drift.
Young Gray Drift.
Lake Duluth bed (outside Lake Superior)
Glacial Lake Agassiz bed on Young Gray Drift.
Lake Agassiz bed on Young Red Drift
0 5 10 20 30 40 50 Miles
Prepared 1916
By Frank Leverett,
and F. W. Sardeson
for
Minnesota Geological Survey
W. H. Emmons, Director

FIGURE 2. MAP OF GLACIAL DRIFTS, LOESS, AND GLACIAL LAKES IN MINNESOTA

The glacial deposits also show some variations that relate to the kind of rock formations over which the ice passed. Thus, the northeastern portion of the state has a rather stony drift from the volcanic and hard crystalline rocks of that region. This stony material was carried as far south as Dakota County and forms the red drift of eastern and northeastern Minnesota. As indicated below, the red drift is the product of more than one ice sheet. The western and southern parts of the state have a large amount of clayey drift material with limestone pebbles imbedded. This material was gathered by this ice as it passed across in its southward course from the shales and limestone of southern Manitoba, that greatly dominate there over the granite and other crystalline rocks. These clayey and limy deposits form what is known as the gray drift of Minnesota, and the ice sheet which formed it, as the Keewatin ice sheet.

STREAM DEPOSITS

The stream deposits, being restricted to the valleys, are of limited area, though in such valleys as the Minnesota and Mississippi they are locally several miles in width and form important agricultural belts. On the Minnesota and the part of the Mississippi below the confluence with the Minnesota the deposits made by the rivers are sand or silt. On the Mississippi above the mouth of the Minnesota the deposits range from sand to coarse cobble and bowlders in correspondence with the swiftness of the stream. On nearly all the tributaries of the Mississippi and Minnesota the streams are able to carry coarse as well as fine material. Along the Red River a considerable amount of fine clay and clay loam has been deposited in seasons of flood on the plains outside the immediate river channel. The deposits made by glacial streams or those which had their sources at the edge of the ice and were receiving much of their water from the melting ice, now appear usually as terraces along the valleys above the limits of floods. From the fact that the glacial rivers were of greater volume these deposits are generally composed of sandy and gravelly material somewhat coarser than that carried by the present rivers.

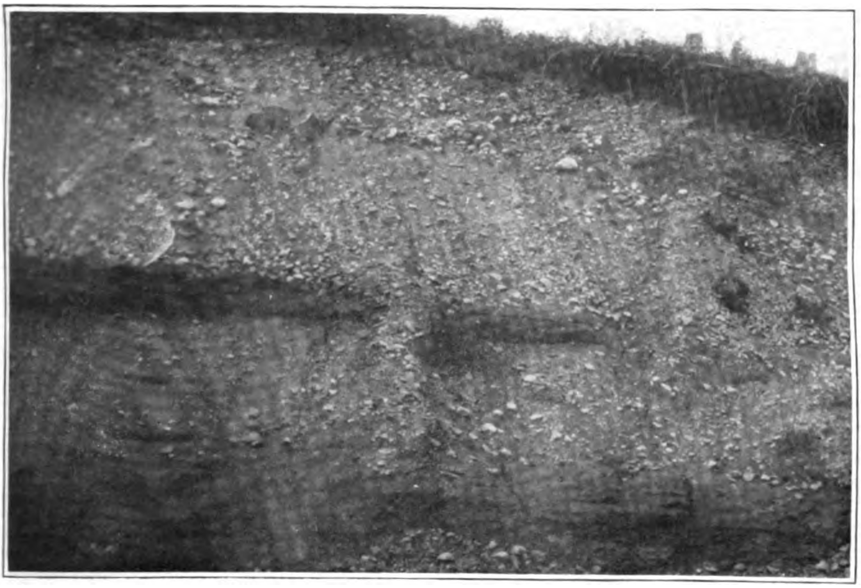
LAKE DEPOSITS

The lake deposits consist of fine sediments washed into the deep parts of the lakes, and sandy and pebbly deposits washed up and formed into beaches along the shores. In parts of the lakes where the glacial deposits which they covered were pebbly and the water was shallow enough for wave action, there was a concentration of stony material by the washing-out of the finer material. By this process considerable areas of the bed of Lake Agassiz were covered by very pebbly beds several inches in depth. They are classed on the soil maps as "lake-washed till." In the narrow strip along the shore of Lake Superior that was covered by the waters of a glacial lake known as Lake Duluth, there is very little fine sediment; gravelly and cobbly beaches were formed at several successive levels, while fine material was washed down into the deeper parts of the basin covered by the present lake. Fine material also covers the old lake plain in Carlton County and a strip on the south side of Lake Superior.

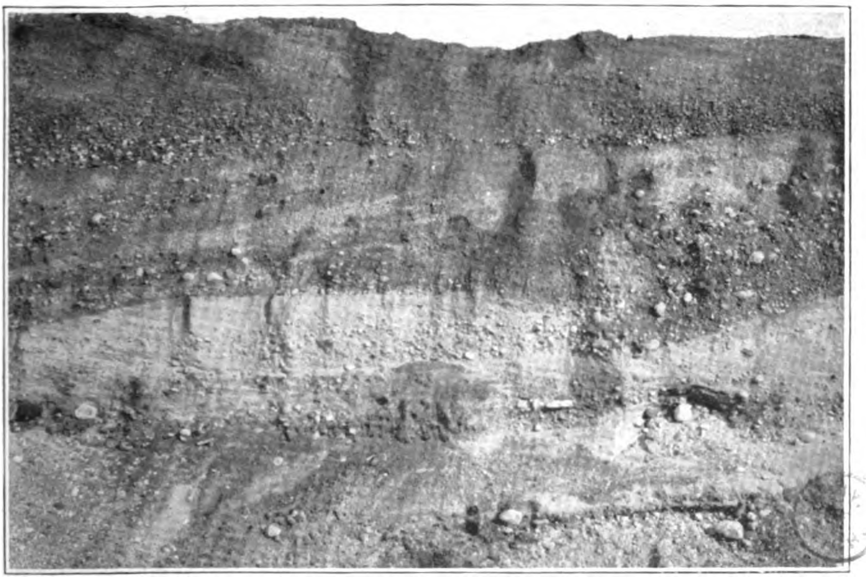
THE GLACIAL FEATURES AND THEIR HISTORY

It has been found through a study of the deposits in Minnesota and neighboring states that the glacial deposits which form so extensive a mantle in Minnesota are the result of more than one invasion of the ice from the Canadian highlands. At each invasion the ice left a deposit of drift gathered partly from Canada and partly from the deposits over which it passed in Minnesota. The advances were so widely separated in time that the drift deposits of one invasion had large valleys cut in them by the action of streams before the next invasion occurred. The later advances failed to reach the limits of the earlier deposits, so they are still exposed to view, and the degree of erosion of the surface of the older can be compared with that on the surface of the younger deposits. It is found that the older drifts have been so greatly eroded and are so ramified by drainage lines that no lakes or undrained basins remain on them, while the younger drift deposits have numerous lakes and undrained basins and also large, poorly drained areas which the streams have not yet reached. It is because they are not covered by the latest drift that Rock and Pipestone counties in southwestern Minnesota, and Goodhue, Dodge, Wabasha, Olmsted, Winona, Fillmore, and Mower counties in southeastern Minnesota have no lakes and basins such as characterize neighboring counties that were covered by that drift.

The invasions of the ice into Minnesota not only took place at different times, but have come from more than one direction at about the same time. In the earlier invasions the greater part of the state was covered by ice coming from Manitoba as shown by limestone fragments and pebbles derived from rock formations of that country which are imbedded in the lower part of the drift over all of the state except its northeast part. The movements in the closing stage of the glacial epoch were more largely from the northeast, but more than half of the state was invaded from the northwest. The ice sheets were as follows: 1. *The Superior lobe of the Labrador ice sheet,* an extension of ice southwestward from the Superior basin nearly to Mille Lacs Lake; 2. *The Patrician ice sheet,* with southward movement from the highlands north of Lake Superior across eastern Minnesota to points a little beyond St. Paul;



A. A GRAVEL OUTWASH IN LAKE COUNTY



B. GRAVEL IN BEACH OF LAKE AGASSIZ. PHOTOGRAPH BY D. W. JOHNSON

3. *The Keewatin ice sheet,* which moved southward through Manitoba and across western Minnesota. After the melting away of the ice that came from the northern highlands, the Keewatin ice sheet extended over some of the ground that ice had vacated. It crossed the Mesabi Range into the St. Louis basin, and also moved northeastward from near Minneapolis into Wisconsin. This advance over earlier drift deposits is known from the presence of a thin deposit of clayey and limy drift containing rock material brought from Manitoba which covers the drift that was deposited by ice coming from the highlands northwest of Lake Superior. The drift from these highlands together with that from the Lake Superior basin forms the stony red drift of eastern Minnesota, while that from Manitoba forms the clayey and limy gray drift which covers almost all of the remainder of the state.

That the ice mass moved in different directions at different times in certain parts of the state is further shown by striations or ice markings on the surfaces of the rock ledges. In the district east and south of the Lake of the Woods a set of glacial grooves or ice markings bears west of south, while a newer set crosses them in an eastward or southeastward direction. The older set was formed by ice moving into Minnesota from the highlands that lie between Lake Superior and Lake Winnipeg, while the younger set was formed by ice moving into the state from Manitoba. In North Minneapolis there are rock ledges on which the glacial grooves have three courses; first, a southeastward course at the time when the old gray drift which came from the northwest was brought in; second, a southward course at a time when the red drift which came from the north was deposited; third, an eastward course at the time when the ice from the northwest advanced over land that had been vacated by the ice which deposited the red drift.

GLACIAL LAKE FEATURES

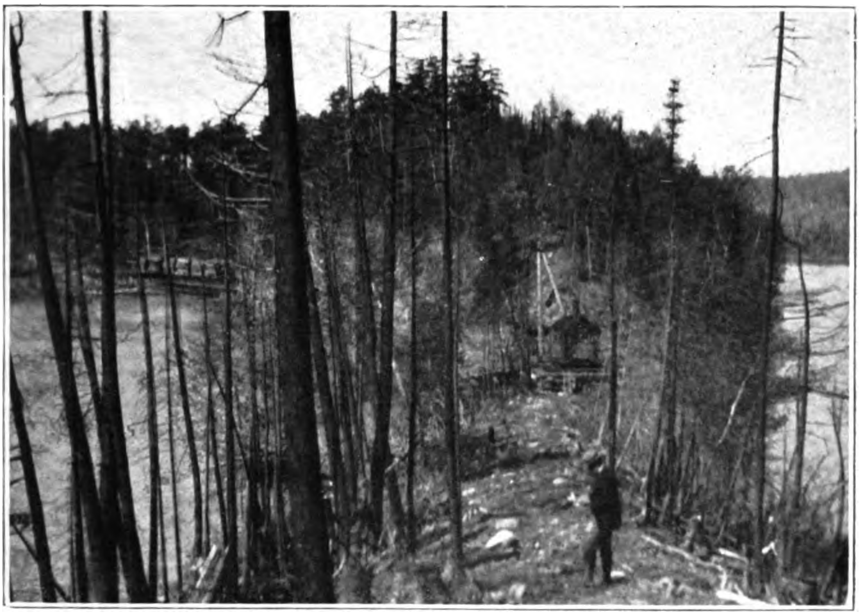
Minnesota contains parts of the beds of two large glacial lakes: Lake Duluth, which occupied the western part of the Superior basin, and Lake Agassiz which occupied the Red River basin. Lake Duluth covered a narrow strip along the shore of Lake Superior and extended a few miles beyond the west end of Lake Superior into eastern Carlton County, Minnesota. Its highest stages were 500 to 700 feet above the present surface of Lake Superior, there being an increasing height toward the northeast corner of the state. Lake Agassiz extended as far south as Lake Traverse, and thence it discharged past Brown Valley to the Minnesota. Its border is only from 20 to 30 miles east from the North Dakota-Minnesota line from Lake Traverse northward to Polk County. About 20 miles east-southeast of Crookston it makes an abrupt eastward turn and continues eastward past the south side of Red Lake and on across Koochiching County into St. Louis County as far as the valley of Little Fork River. It then turns northward and enters Canada from northeastern St. Louis County. There were several islands in it in northern St. Louis County.

Preceding the development of the large glacial Lake Agassiz there was a temporary ponding of waters in front of the ice in Koochiching, Itasca, and St. Louis counties at a level higher than that of Lake Agassiz, and a discharge of the waters southward across the Mesabi Iron Range into the St. Louis basin along the course of the Embarrass River. With the melting back of the ice border this lake became merged with Lake Agassiz, and its waters then discharged into the Minnesota valley.

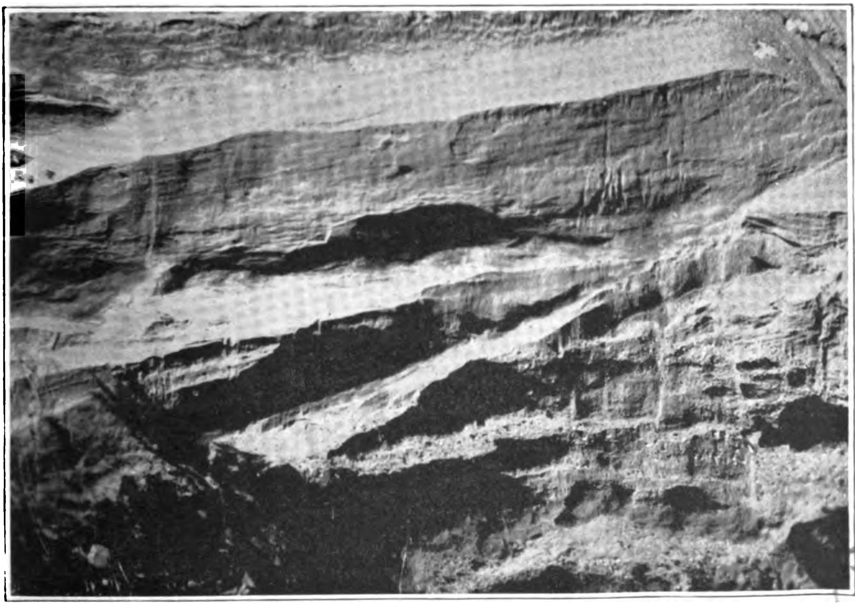
There were also two noteworthy temporary lakes in northeastern Minnesota which were not held up by ice barriers, but instead by land barriers along their outlets. When these were cut away the lakes became drained. One of these, named Lake Aitkin by Upham, occupied the plain bordering the Mississippi in Aitkin County and extended a short distance into eastern Crow Wing County. It was drained by the erosion of the Mississippi valley at its lower end just above Brainerd. The other lake, named Lake Upham by Winchell, occupied a considerable part of the St. Louis basin in western St. Louis County. It was drained by the erosion of the St. Louis valley below Floodwood.

Prominent features of the two great glacial lakes, Lake Agassiz and Lake Duluth, are the beaches or ridges of sand and gravel washed up along their shores. The shores of Lake Agassiz stand high and dry above the flat parts of the lake bed between or below them and form excellent lines for highways. For this reason much of the pioneer settlement and travel was along these ridges. They generally stand from 5 to 10 feet above the bordering plains and occasionally from 15 to 20 feet. On the inner or lakeward side they are generally more prominent than on the outer or landward side. This is due in part to the original slope toward the center of the lake, but there is also a tendency for a lake to eat back into the bordering land and throw its coarser material up on the edge of the plain outside; at the same time the fine material is carried in suspension from the shore into the deeper water.

The levels of these glacial lakes were lowered from time to time, partly by the cutting-down of the outlets and partly by an uplift of this region which caused the water to fall away where the land rose. There was also a change of outlet in Lake Agassiz from the southern end to the northern and in Lake Duluth from the southward outlet into the St. Croix River to an eastward outlet into the Lake Huron basin. As a result shore lines were formed at various levels on the slopes of the



A. ESKER BETWEEN LAKES IN EASTERN LAKE COUNTY. PHOTO BY A. H. ELFTMAN



B. INTERIOR STRUCTURE OF AN ESKER IN LAKE COUNTY. PHOTO BY A. H. ELFTMAN

old lake beds. Because of the gradual lowering of the water level the greater part of the beds of these glacial lakes has at some time been subjected to wave action. This has produced a widespread pebbly coating which is a concentrate from the washing of the surface of the bowlder clay and the carrying-away of its finer material. Where the bowlder clay was sandy, the sand as well as stones remain, but where it was clayey there is often a clear bed of pebbles a few inches in depth covering the clayey till subsoil. The deep part of Lake Agassiz along the borders of Red River received nearly all the fine sediment which was washed out from the till at higher levels. This forms the bulk of the rich black clay and clay loam of the Red River basin. At its eastern border, fifteen to twenty-five miles from Red River, there is a transition to sand. This is succeeded within two to five miles east by stony sandy deposits which seem to be a glacial material worked over by the lake.

GENERAL SOIL CONDITIONS

Soil is composed of materials derived from the subsoil and mixed with organic matter. Subsoil is the weathered and disintegrated top of the underlying geological formation. For its qualities and composition the soil of a given region therefore depends quite closely upon the nature of the geological formations there exposed. In Minnesota the land mantle of glacial and lake deposits affords a well-mixed and rich supply of materials suited for soil-making. This is particularly true where it consists of till or bowlder clay in which all classes of material are loosely but thoroughly mixed. This contrasts with soils in which there is too much uniformity and which, when of water-washed sand or gravel, are often deficient in fine material. On the other hand, the loess and the lake silts, though of somewhat uniform texture, make rich soils because of the variety of finely divided minerals which they contain.

The soil and its productiveness depends largely upon the drainage conditions. A soil of clay or clay loam over gravel or loose sand suffers in time of deficient rainfall, while in wet seasons a soil resting upon heavy clay may be drowned out unless surface drainage is perfectly adjusted. For this reason the geologic formation underlying a soil is of great importance. Soil underlaid by limestone, by loess, or by a till consisting of a light clay, or a heavy loam will stand great variation in rainfall and still be highly productive. In some parts of the state the surface drainage is naturally well developed, while in other parts it needs to be greatly supplemented by tile draining or surface ditching.

In the Driftless Area the drainage on the uplands is everywhere complete, for nearly every acre slopes toward some drainage line. In the old drift also there are few undrained areas and tiling or surface ditching is seldom necessary. In the young drift there are many basins, and undrained depressions and drainage lines are not well distributed over the surface. Except, therefore, where the material is loose enough for the rainfall to be absorbed completely the young drift areas need considerable ditching and tiling. In the bed of Lake Agassiz, although basins and depressions are rare, there are wide areas where the surface is very flat and extensive and systematic tiling or ditching is required to keep the land from being flooded.

VEGETATION

The condition of the soil depends to some degree upon the character of the vegetation which has covered it. In prairie districts there is a more uniform exposure to weathering agencies than in forested districts and consequently a more uniform soil is developed on a given deposit. On the whole, leaching of lime seems to be less rapid on prairies than in forests so that in the newer drift limestones are often present at the surface in prairies, but in the forested areas limestones are usually dissolved out to a depth of some inches and often to some feet from the surface. On the older drift the limestone is generally removed to a depth of several feet both in prairie and forest, but the leaching is perceptibly deeper in the forested areas. The rate of erosion and removal of soil is more uniform in prairie than in forested tracts. It takes more force to dislodge the trees than the grassy vegetation on hillside slopes, and erosion in the forests is likely to become concentrated in occasional gullies, whereas on prairies there are many small channels developed on every hillside which serve to break it down rapidly. On the whole, therefore, erosion is greater but leaching is less in prairie than in forested areas.

The forests occur only on protected slopes in much of southern Minnesota and are absent from such slopes in much of the western part of the state (Figure 3). In the central and northeastern parts they cover plains or uplands as well as valley slopes. The muskegs, which have a scanty forest growth, are developed chiefly in the northern half of the state and chiefly within the forested area.

WEATHERING

There are parts of the newer drift in which fresh material is close to the surface so that they can scarcely be said to have a subsoil different from the drift sheet as a whole. There are also places on valley slopes in the older drift where unweathered material is close to the surface, because erosion keeps pace with the weathering of the drift. At most places, however, the older drift has a mantle of weathered material several feet in thickness, while that of the younger drift is only one or two

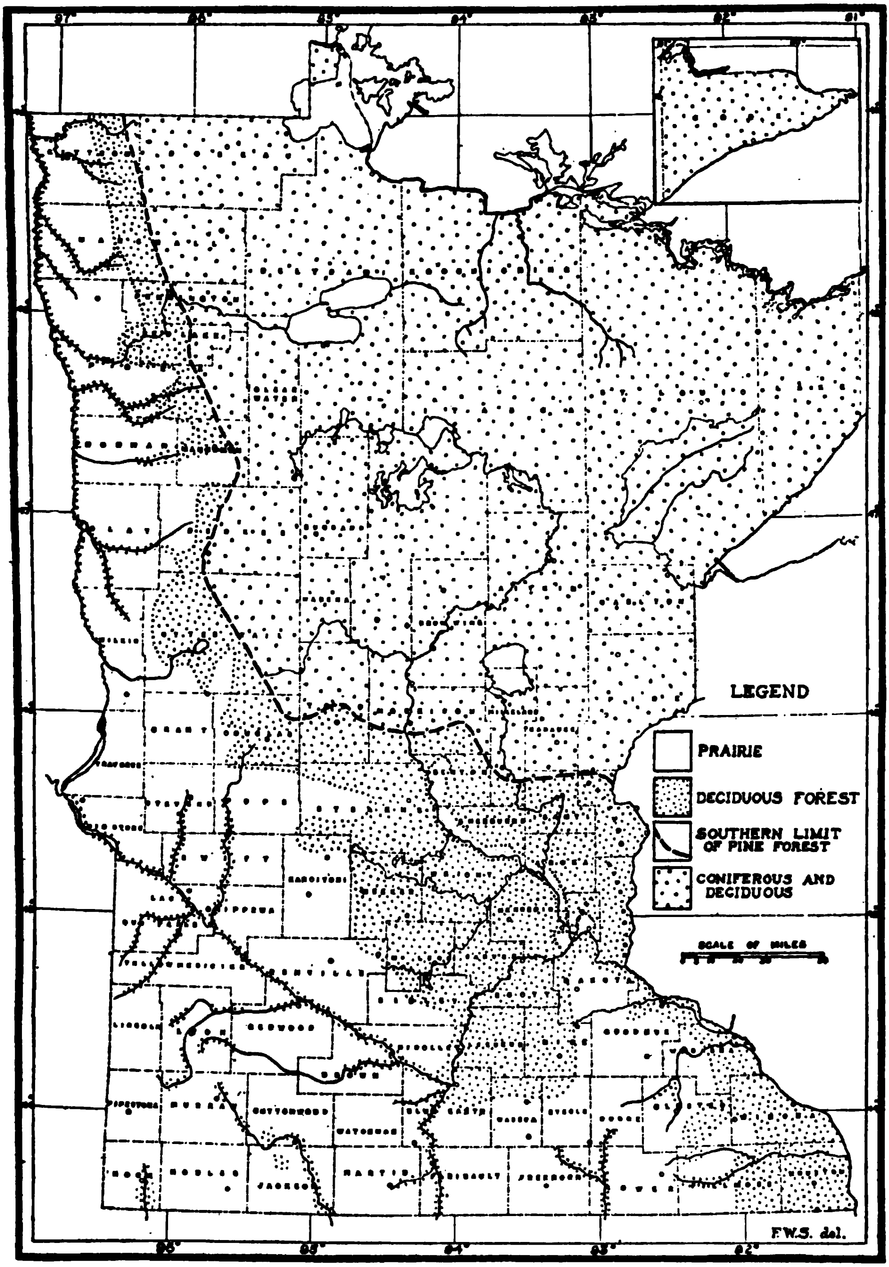


FIGURE 3. MAP OF MINNESOTA SHOWING DISTRIBUTION OF FOREST AND PRAIRIE. (AFTER MAP BY WARREN UPHAM AND BY FREDERIC K. BUTTERS)

feet thick. In this the feldspar and other minerals are disintegrated and made ready for plant food.

Weathering in the loess-covered areas is moderately deep, as it is in the older drift. The entire deposit of loess, however, is of fine texture and is found to be very fertile from top to bottom.

LIME

While most of the soils of the northwestern part of the state seem abundantly supplied with lime, it is probable that some of the more sandy ones would give a sufficiently greater yield of certain crops to make it profitable to purchase some form of lime if this could be obtained at a low price. Usually when a soil needs lime, it is advisable to apply one ton or more of ground limestone or marl per acre. If this has to be shipped any considerable distance, the freight charges may greatly exceed the cost of the material on board of the cars at the point of shipment. For this reason it is important to locate a supply as near as possible to the place where it is to be used.

Lime occurs abundantly in two forms in Minnesota: as bog-lime or marl, and as limestone. The marl is unconsolidated and easily pulverized. It needs no crushing or grinding. Limestone is consolidated and must be crushed or ground for use on fields.

Marl is found in Minnesota in many lakes and under some bogs that have been lakes. It is of most frequent occurrence in the central and north central part of the state. It lies always in low wet ground and can be found, as a rule, only by boring or ditching. It is a soft, white or gray, chalky material. Since it needs no crushing or grinding, the cost of the marl is in the finding, ditching and draining, or drying of it. Deposits from 1 to 10 feet in thickness and covering from 1 to 100 acres are known to be of common occurrence.

Limestone formations outcrop in the bluffs along the Mississippi and its tributaries in southeastern Minnesota. The formations lie horizontally and are of wide extent, or practically continuous for many miles. Limestone formations 100 feet or more thick extend along the valleys from the southeastern corner of the state to Stillwater, Minneapolis, Mankato, Austin, and intermediate points. An inexhaustible supply of limestone is easily found in outcrops that are high, so that quarrying, crushing, and loading can all be done in a down-hill direction, the cost of production being thereby lessened.

EFFECT OF FIRES

There are large areas in Minnesota which have been swept by forest fires, and these fires have destroyed much of the accumulated leaf mold.

In sandy areas the destruction of the leaf mold may have reduced somewhat the productiveness of the land, for the leaf mold acts as a mulch to prevent the drying out of the soil. But in clayey areas there seems to have been very little reduction of the fertility. The leaf mold in such places, however, when turned under has a beneficial effect in loosening the stiff clay. A large area of clay land in the Little Fork drainage basin in St. Louis and southeastern Koochiching counties was burned over some fifty or more years ago, according to statements of the Indians, and the leaf mold was almost completely destroyed. A heavy growth of poplar has sprung up on the drier parts instead of the mixed hardwood that had occupied the land, while the wet areas have a fresh stand of spruce (See Plate XIVA). This district is being rapidly cleared and is producing exceptionally good crops. The forest fire near Hinckley in Pine County, which occurred about twenty-five years ago, swept over an area chiefly of till much of which is loose-textured. This had a similar effect in changing the forest from mixed hardwood and pine to poplar. This area is now one of marked agricultural fertility adapted to a variety of crops. The principal damage by fire in this state, both past and prospective, seems to be in the destruction of peat in the bogs. In such cases there is not only the loss of a valuable fuel, but the land is left in a rough state ill-suited for cultivation.

CHAPTER II

CLIMATIC CONDITIONS OF MINNESOTA

By U. G. Purssell
Director of the Minnesota Section of the United States Weather Bureau

INTRODUCTION

The agriculture of any region is controlled by its climate. In some parts of the world temperature is the main factor in determining the limits of growth of certain kinds of crops; in others it is rainfall, and in still others it is the amount of sunshine. All of these factors are important in influencing the crop yield even in districts where the general climatic conditions are satisfactory for the growth of plants. In Minnesota these elements are so favorable that a majority of the crops common to the temperate zone may be successfully grown, and a failure of all the important crops is very rare even over a small portion of the state.

Rainfall is an important factor for most crops in the state, because the proper amount of water in the soil at the critical period of development of the plant is necessary to produce a large crop. The length of the growing season also is important and probably no other factor in the study of climate from the standpoint of the agriculturist should be given more consideration. This is the key to an actual knowledge as to the possibilities of success or failure in the production of crops since in parts of the state crops are menaced by frost at some period of their growth, whereas sunshine and moisture seldom vary in Minnesota beyond safe limits.

The factors which determine the climate of any area are the relative distribution of land and water, the topography of the land surface, and the situation of the area in question with relation to the general movement of the cyclones and anti-cyclones.

The position of Minnesota at the center of North America gives it a climate that is largely continental. In continental climates the temperature extremes are greater and the humidity and rainfall generally less than at places near large bodies of water, such as border on the Atlantic, Pacific, and Gulf coasts of the United States. The effect of winds from great bodies of water is to equalize temperatures of lands near by and to lengthen materially the crop-growing season. This is particularly true of the country in the vicinity of Lake Superior, where the influence of that great inland sea in modifying the cold anti-cyclones gives to that section a more equable climate than would otherwise obtain in that portion of the state. The summer temperatures are likewise modified and people from long distances inland in steadily increasing numbers are establishing summer homes about the lake, to which they are attracted during the hot summer months. There are more than 7,000 small lakes scattered throughout the state and these have a material local influence in modifying the heat of summer and give comfort to thousands of residents on their shores.

Monthly and annual reports of temperature, rainfall, snowfall, etc., have been published for a large number of regular and coöperative stations in Minnesota since 1895. Recently three special section reports have been issued by the United States Weather Bureau giving monthly and annual precipitation totals for all points in the state with a record of ten years or over, together with average temperatures and other data. In these reports the more important facts from all portions of the state are tabulated and the comparative climatic conditions of the different sections graphically shown.

GENERAL CLIMATIC CONDITIONS

Minnesota is in the path of a large proportion of the low-pressure areas which move across the United States from west to east. These areas move at an average speed of 600 miles in twenty-four hours and are preceded by southerly winds and higher temperature and followed by northerly winds and lower temperature. They are usually accompanied by cloudy weather and precipitation; each storm causing an average of from one to two rainy days as it crosses the state.

As there is an average of almost two of these storms each week with fair weather periods between, it follows that the changes in weather conditions are rather rapid. One or two days of stormy weather preceded by fair weather and followed by clearing and lower temperatures to be repeated in turn, make up the usual routine for the week. However, Minnesota is so far from the coast that damaging ocean storms lose much of their severity before reaching its borders.

The northwestern cold waves pass across the state and send their health-giving winds into all parts, and yet they are frequently not so severe as they are in some of the plains states in the same latitude or even farther south.

Temperature.—The average annual temperature of Minnesota for the period 1895 to 1913 inclusive, is 41.7°, as shown in Table I and graphically by Figure 4. The highest annual mean temperature, 43.9°, occurred in 1900, and the lowest, 39.9°, in 1912. The departure of the average temperature of any year from the normal may readily be deter-

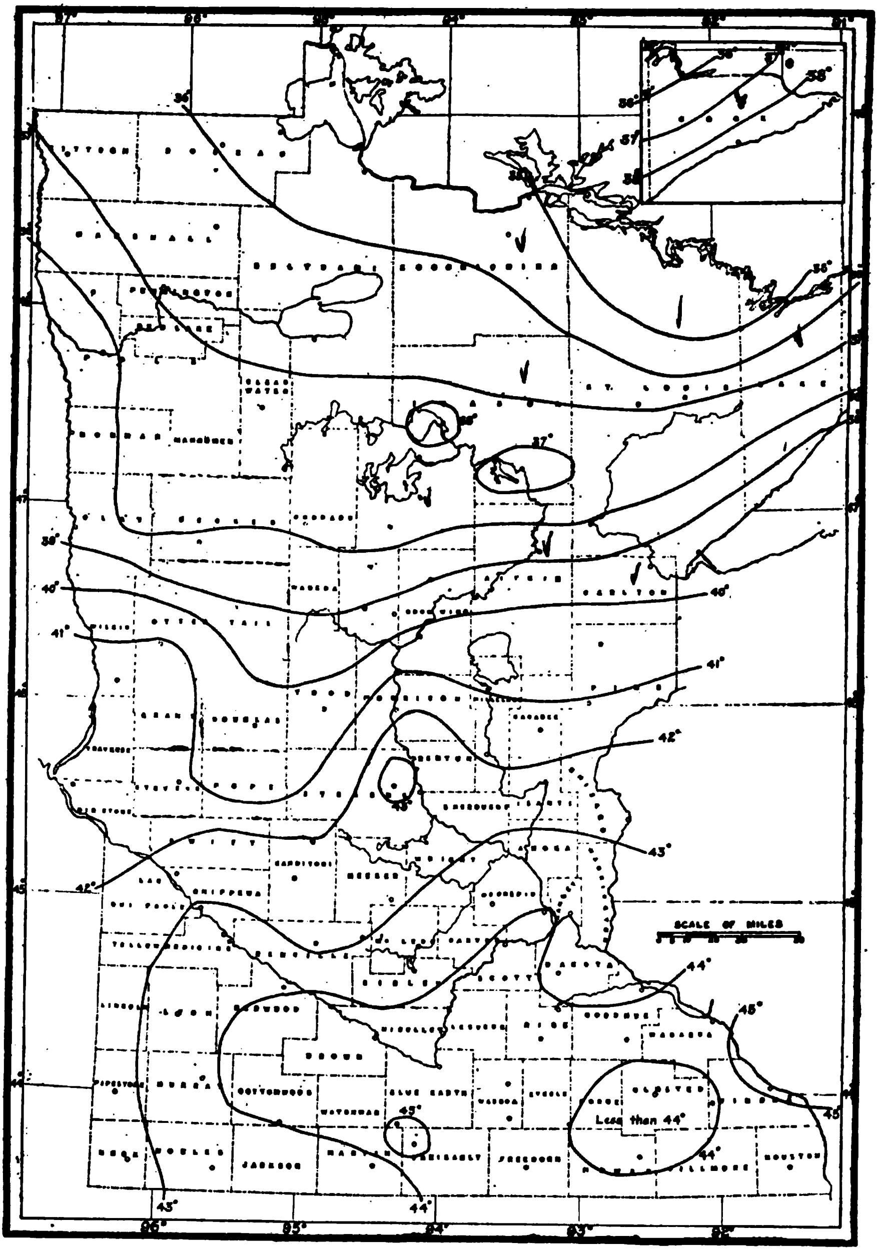


FIGURE 4. MAP SHOWING MEAN ANNUAL TEMPERATURES OF MINNESOTA (DEGREES FAHRENHEIT)

mined by comparing the yearly average with the mean at the foot of the column.

Table I. Monthly and Annual Mean Temperature for Minnesota (Degrees Fahrenheit)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1895	.....	.....	.....	49.9	56.9	64.6	67.8	67.4	61.5	41.4	27.8	18.3	......
1896	12.3	17.9	21.4	44.5	60.9	66.5	69.9	67.9	54.3	42.4	18.0	20.3	41.6
1897	7.2	15.3	20.7	43.7	55.2	62.5	71.6	64.2	65.3	50.0	26.6	12.3	41.2
1898	18.3	16.4	30.3	43.5	55.6	67.0	69.8	66.9	60.6	42.9	26.6	11.9	42.2
1899	9.9	4.5	14.7	44.0	55.1	65.4	70.2	69.1	56.4	49.0	39.6	17.9	41.2
1900	18.4	5.2	23.4	49.5	59.9	66.8	68.8	74.3	58.2	55.1	25.4	18.6	43.9
1901	13.2	10.0	27.3	46.7	58.2	65.5	74.7	69.8	57.3	49.2	28.8	13.0	42.8
1902	15.9	15.5	34.0	42.6	57.0	61.3	69.7	65.2	55.2	47.1	33.3	12.6	42.6
1903	11.3	10.6	29.6	43.3	55.7	62.3	67.2	63.6	55.5	46.1	27.3	9.8	40.3
1904	4.5	2.3	24.8	38.8	55.4	63.2	66.0	64.9	57.4	47.4	36.7	16.7	40.1
1905	5.6	8.9	33.7	42.0	52.6	63.0	67.3	68.9	61.9	43.5	33.1	20.6	41.5
1906	17.0	13.8	20.6	47.9	53.7	63.7	68.3	68.7	63.3	45.7	30.7	15.9	42.0
1907	3.8	14.8	28.7	34.7	45.5	63.3	68.2	66.1	55.9	45.4	31.7	21.3	40.1
1908	16.4	17.9	26.4	45.2	53.9	62.5	69.4	65.5	64.2	47.0	33.8	17.5	43.4
1909	10.5	13.7	26.1	35.8	53.2	65.0	69.2	70.9	58.7	44.7	33.8	10.0	41.0
1910	11.8	7.5	41.7	48.0	51.6	67.8	70.6	65.8	58.4	50.8	25.3	14.7	42.8
1911	5.4	16.6	32.7	42.7	59.8	69.7	68.2	64.0	56.7	43.4	20.2	19.4	41.6
1912	—6.7	10.6	19.8	45.5	55.9	62.5	68.5	63.9	57.2	47.5	33.9	20.0	39.9
1913	7.2	8.6	20.4	46.4	52.7	67.4	67.3	69.2	58.6	42.7	36.9	26.1	42.0
1914	16.9	2.8	26.6	41.2	57.6	64.6	72.4	66.1	60.0	52.6	33.0	.....	......
Mean....	10.5	11.2	26.5	43.8	55.3	64.7	69.3	67.1	58.8	46.5	30.1	16.7	41.7

The coldest month is January, which has a mean temperature of 10.5°, although the average for February is only 0.7° higher. In a great many instances February has averaged colder than the preceding January. This condition occurred in the seven successive years from 1898 to 1904 inclusive. Average January temperatures are plotted on Figure 5.

July is the warmest month, with an average temperature of 69.3°, although in a few years the mean temperature for June or for August is higher than for July of the same year. Average July temperatures are plotted on Figure 6.

The highest summer mean, 70.0°, occurred in 1900 and 1901 (Table II). The coldest summer was that of 1903, with an average of 64.4°.

The warmest crop-growing season (April to September inclusive) of the eighteen years under discussion was in 1900, when the average was 62.9°, and the coldest was in 1907, with an average of 55.6°.

The warmest winter (December to February inclusive) was in 1907-8, when the mean temperature was 18.5°. The coldest was in 1903-4, with a mean temperature of 5.5°. Table II shows also the warmest and coldest spring and autumn.

In Figures 7 and 8 are shown the highest and lowest temperatures ever recorded in the various counties where records have been kept. From these figures it can readily be seen that the extreme range of temperature is from 107° at Grand Meadow and Milan, to —59° at Leech Lake Dam and Pokegama Falls. Temperatures above 100° have been recorded in all counties except those about the headwaters of the Missis-

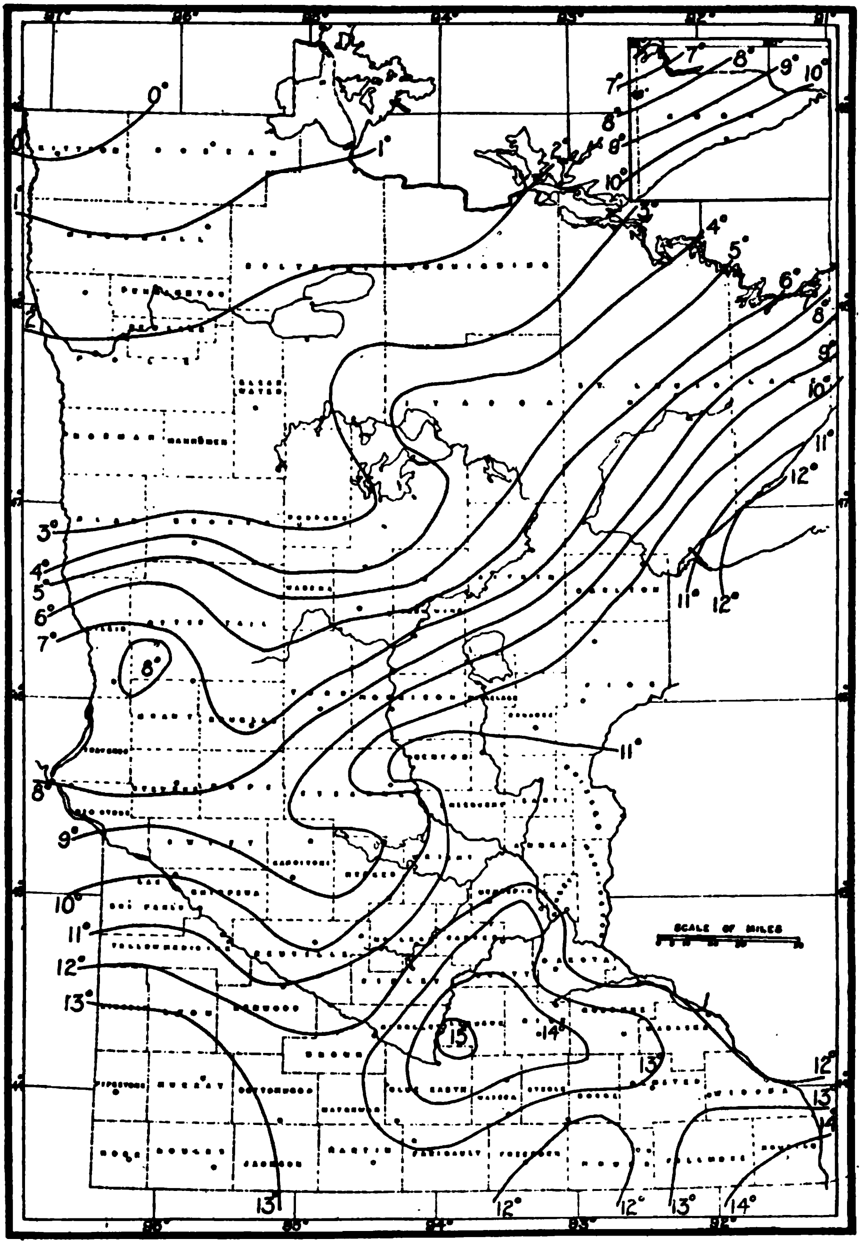


FIGURE 5. MAP SHOWING MEAN TEMPERATURES OF MINNESOTA FOR JANUARY (DEGREES FAHRENHEIT)

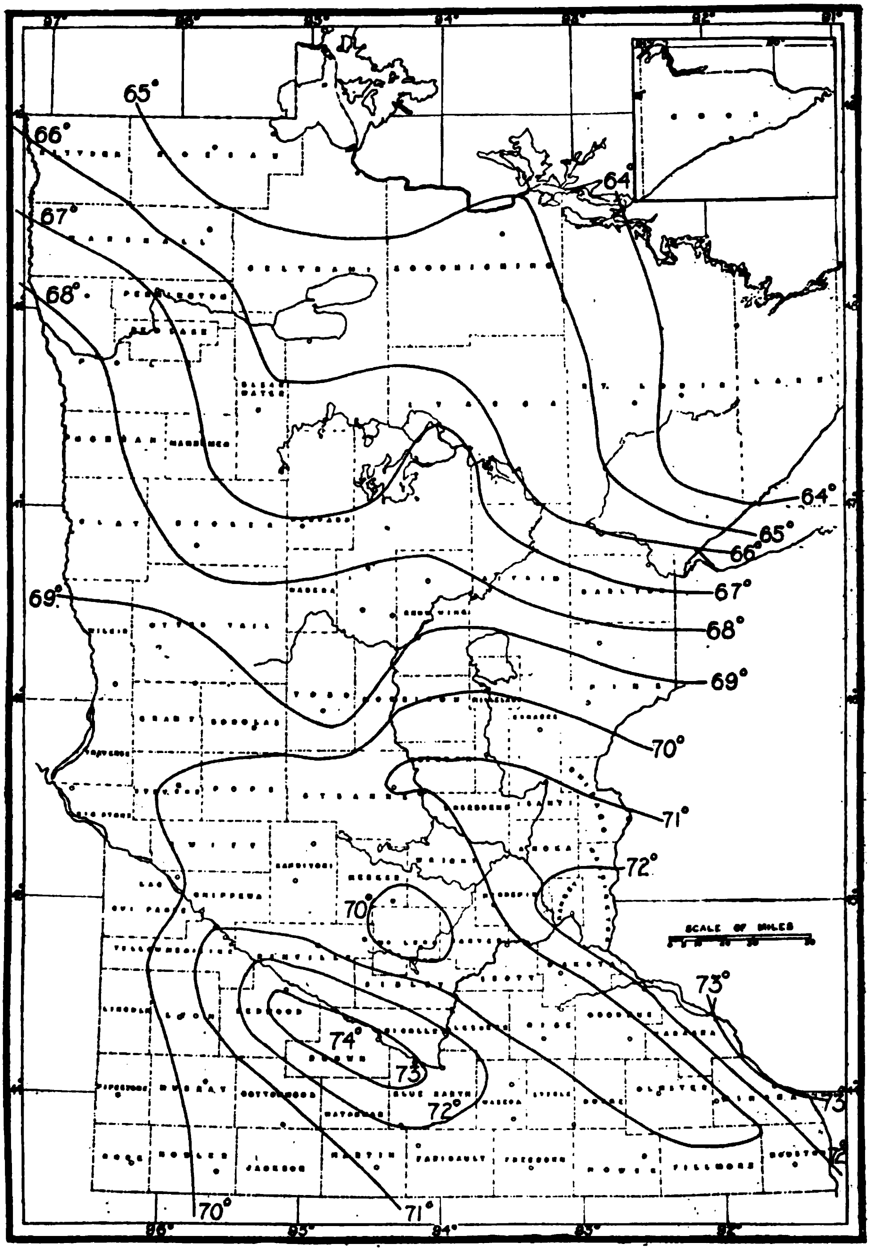


FIGURE 6. MAP SHOWING MEAN TEMPERATURES OF MINNESOTA FOR JULY (DEGREES FAHRENHEIT)

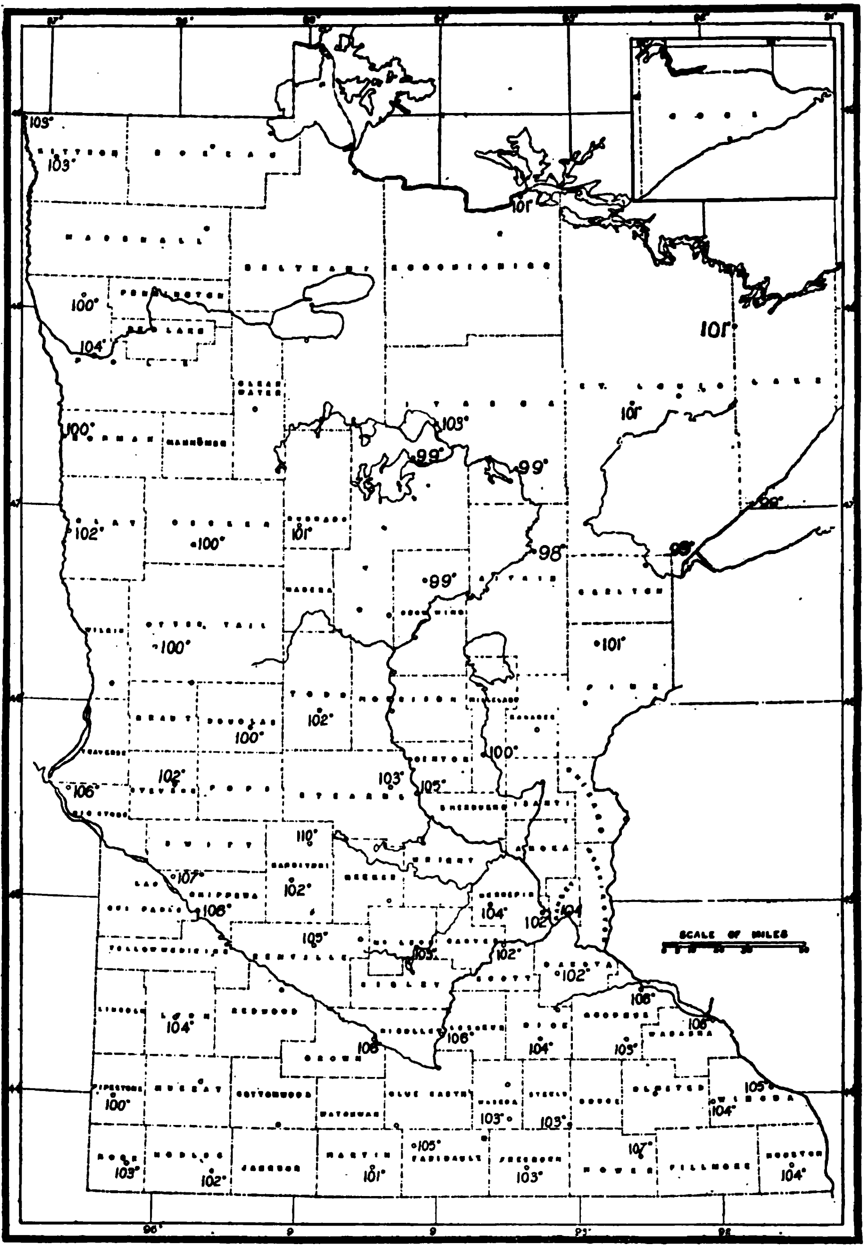


FIGURE 7. MAP SHOWING HIGHEST KNOWN TEMPERATURES IN MINNESOTA (DEGREES FAHRENHEIT)

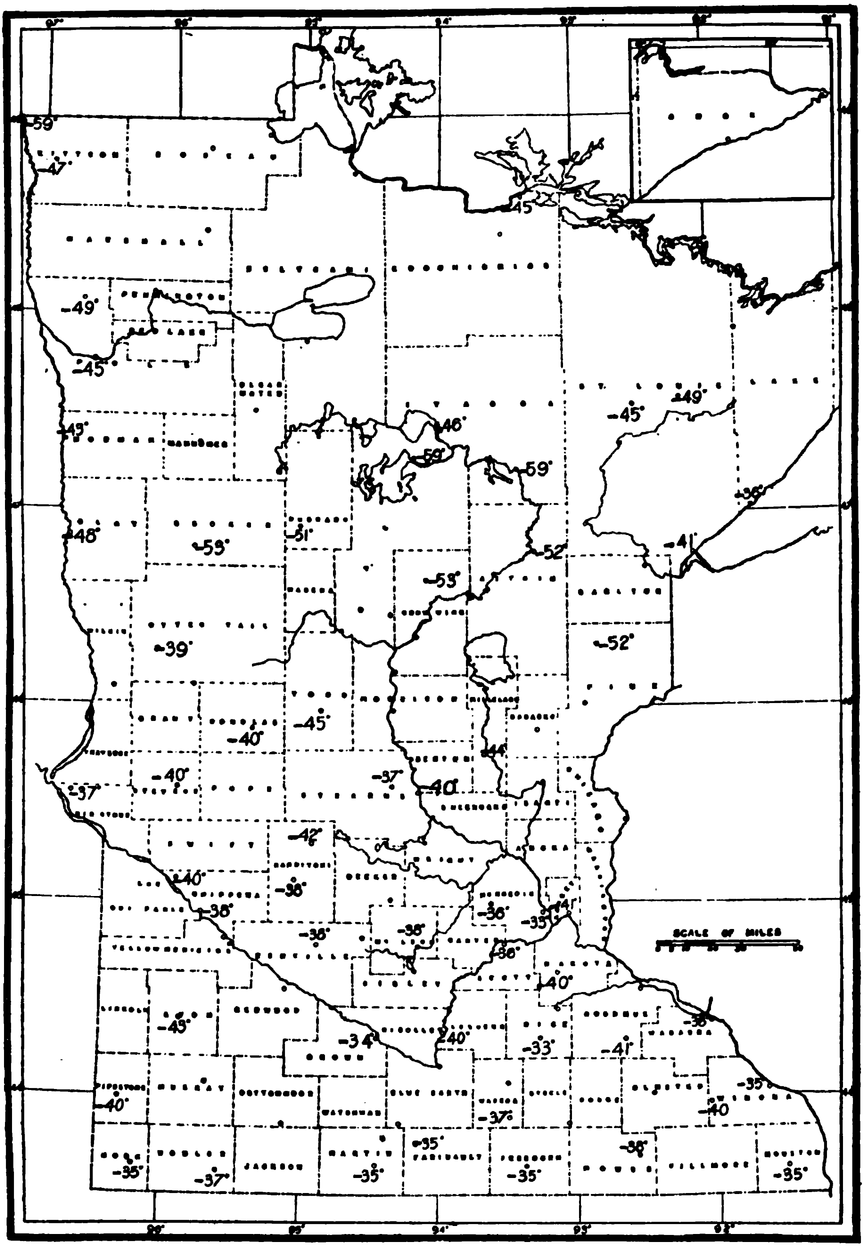


FIGURE 8. MAP SHOWING LOWEST KNOWN TEMPERATURES IN MINNESOTA (DEGREES FAHRENHEIT)

sippi River, and in the country immediately bordering on Lake Superior. Temperatures of —40° have occurred in nearly all northern and central counties and in a few southern counties, but these great extremes do not occur frequently.

Table II. Seasonal Temperatures for Minnesota (Degrees Fahrenheit)

Year	Winter mean	Spring mean	Summer mean	Fall mean	April to Sept. inclusive (crop-growing season)
1895	....	....	....	....	61.4
1896	16.2	42.3	68.1	38.2	60.7
1897	14.3	39.9	66.1	47.3	60.4
1898	15.7	43.1	67.9	43.4	60.6
1899	8.8	37.9	68.2	48.3	60.0
1900	13.8	44.3	70.0	46.2	62.9
1901	13.9	44.1	70.0	45.1	62.0
1902	14.8	44.5	65.4	45.2	58.5
1903	11.5	42.9	64.4	43.0	57.9
1904	5.5	40.0	64.7	47.2	57.6
1905	10.4	42.8	66.4	46.2	59.3
1906	17.1	40.7	66.9	46.6	60.9
1907	11.5	36.3	65.9	44.3	55.6
1908	18.5	41.8	65.8	48.3	60.1
1909	13.9	38.4	68.4	45.7	58.8
1910	9.8	47.1	68.1	44.8	60.4
1911	12.2	45.1	67.3	40.1	60.2
1912	7.8	40.4	65.0	46.2	58.9
1913	11.9	39.8	68.0	46.1	60.3
1914	15.3	41.8	67.7	48.5	60.3
Mean	12.8	41.7	67.0	45.3	59.8

Frosts.—Although frosts have occurred in some portions of the state every month of the year, damaging temperatures are not to be expected during June, July, and August, and they are comparatively rare in the last half of May and the first half of September. Records of ten or more years are available from a large number of places in the state, of which charts have been constructed showing the average date of the last killing frost in spring and the first one in autumn. Using these dates as boundaries, we can mark the average beginning and ending of crop growth and determine the average length of the growing season. All of this information is graphically shown in Figures 9, 10, and 11. By reference to Figure 11 the influence of Lake Superior in lengthening the crop-growing season in its vicinity may be seen; while in the same latitude in the highlands of Hubbard, Becker, eastern Mahnomen, and Clearwater counties the season is twenty to thirty days shorter. The longest season, 160 days, obtains along the Mississippi River from Hennepin County to the southeastern corner of the state, and the shortest, 100 days or less, is in the region of the Mesabi and Vermilion Iron ranges.

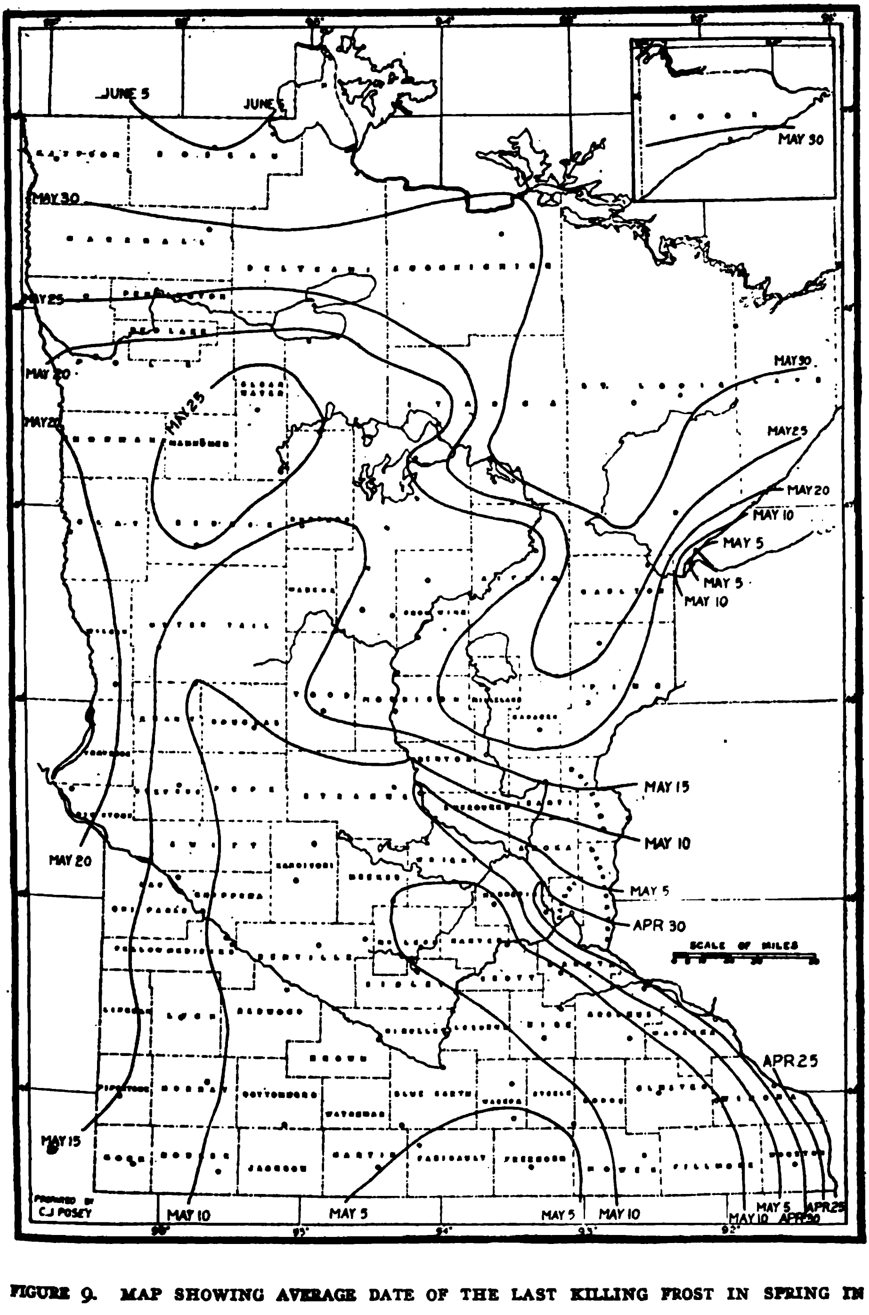


FIGURE 9. MAP SHOWING AVERAGE DATE OF THE LAST KILLING FROST IN SPRING IN MINNESOTA

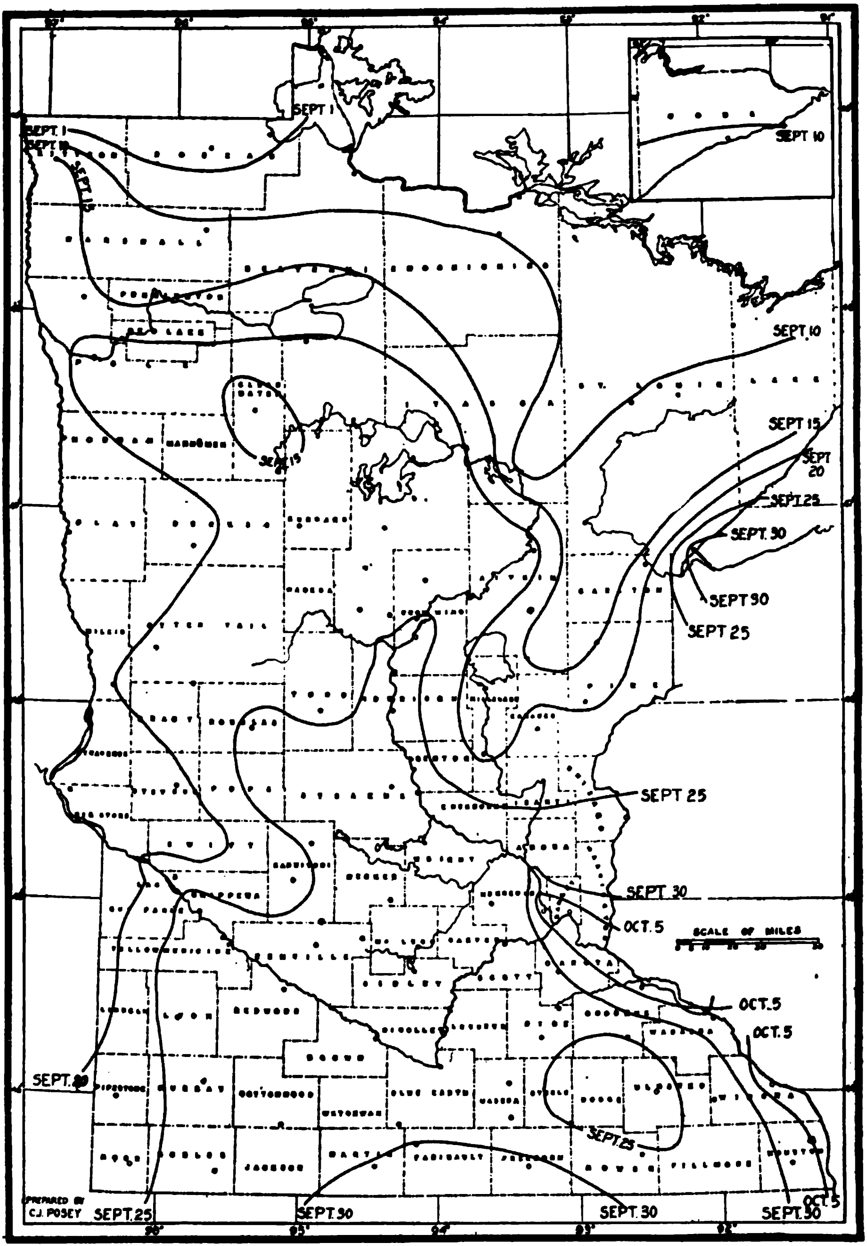


FIGURE 10. MAP SHOWING AVERAGE DATE OF FIRST KILLING FROST IN AUTUMN IN MINNESOTA

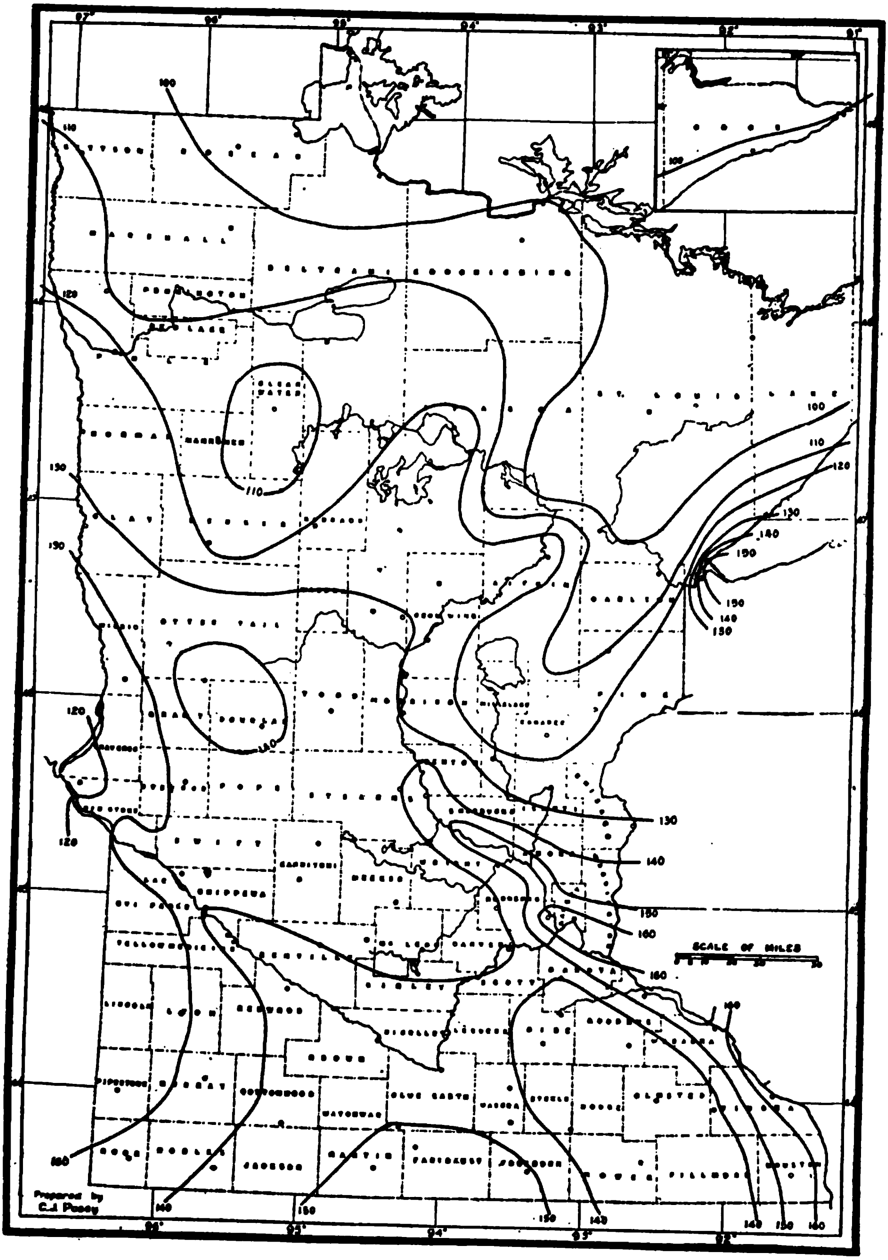


FIGURE II. MAP SHOWING NUMBER OF DAYS OF THE AVERAGE CROP-GROWING SEASON IN MINNESOTA

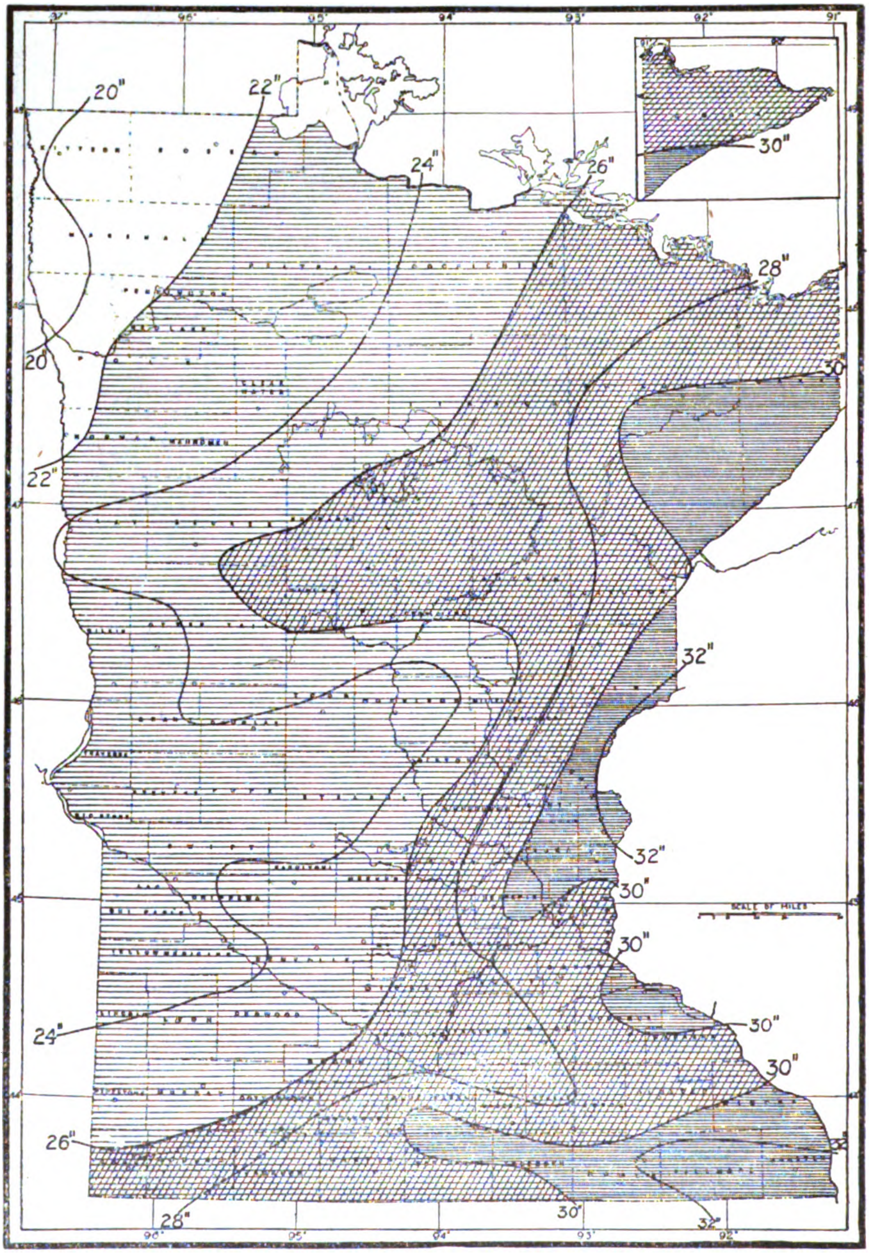


FIGURE 12. MAP SHOWING THE AVERAGE ANNUAL PRECIPITATION FOR MINNESOTA

Table III. Average Monthly and Annual Precipitation for Minnesota (in Inches)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Total April to Sept. incl.
1895	....	....	....	1.68	3.30	4.37	3.25	2.27	3.93	0.25	1.22	0.28	.....	18.80
1896	0.76	0.39	1.97	5.91	5.02	4.07	1.88	2.28	2.49	2.95	2.69	0.61	32.04	21.65
1897	1.77	1.21	2.07	1.55	1.38	5.40	6.62	2.54	1.89	1.55	0.53	0.38	27.23	19.38
1898	0.16	1.02	1.21	1.64	3.26	3.93	2.94	3.22	1.52	3.83	1.02	0.18	24.21	16.51
1899	0.60	0.78	1.58	1.49	4.46	6.36	2.84	5.35	1.47	3.22	0.63	0.95	30.14	21.97
1900	0.48	0.56	1.30	1.47	0.90	1.71	5.48	6.44	6.55	3.85	0.62	0.51	29.79	22.55
1901	0.38	0.40	1.68	1.73	1.41	5.81	3.33	2.21	4.34	1.86	0.78	0.57	24.26	18.83
1902	0.44	0.67	0.92	1.67	5.10	3.32	4.76	4.35	2.23	1.93	1.57	1.79	29.46	21.43
1903	0.45	0.59	1.75	2.82	5.37	1.96	5.11	4.65	5.63	3.13	0.35	0.84	32.85	25.54
1904	0.39	0.62	1.51	1.72	2.43	4.26	3.96	2.77	3.14	3.50	0.14	0.82	29.65	18.28
1905	0.65	0.55	1.21	1.46	5.54	6.41	4.12	4.36	3.45	2.53	2.64	0.15	33.10	25.34
1906	1.15	0.27	1.20	1.72	5.58	4.55	2.93	4.66	3.73	2.28	1.82	0.91	31.66	23.17
1907	1.17	0.58	0.94	1.01	2.14	4.31	3.57	4.11	3.48	1.31	0.57	0.57	24.03	18.62
1908	0.31	1.11	1.47	2.55	6.31	6.35	3.21	2.07	2.41	1.91	1.18	0.79	29.49	22.90
1909	1.32	1.31	0.54	1.89	3.36	3.53	3.84	5.54	3.16	1.56	2.68	1.54	29.27	20.32
1910	0.83	0.45	0.27	1.54	1.58	1.39	1.94	2.35	2.45	0.97	0.52	0.44	14.73	11.25
1911	0.81	0.88	0.63	1.88	3.48	3.79	3.61	4.27	3.35	3.93	1.12	1.35	29.10	20.38
1912	0.40	0.21	0.45	2.04	4.13	1.66	4.30	3.97	3.03	0.97	0.36	0.93	22.45	19.13
1913	0.33	0.44	1.27	1.87	3.53	3.08	5.56	2.79	3.33	2.58	0.66	0.05	25.49	20.16
1914	0.81	0.44	1.12	2.41	2.89	8.34	2.48	3.97	3.08	2.00	0.38	....	.....	23.77
Mean	0.70	0.66	1.22	2.00	3.56	4.18	3.79	3.66	3.23	2.31	1.07	0.71	27.72	20.33

Precipitation.—The annual average precipitation of the state as a whole for a period of eighteen years, 1896 to 1914 inclusive, is 27.72 inches, and for the crop season, April to September inclusive, for twenty years, 1895 to 1913, is 20.33 inches. The monthly, seasonal, and annual averages for this period are shown in Table III. The year with the greatest annual rainfall was 1905, when the total was 33.10 inches. The driest year was 1910 with 14.73 inches. In that year the rainfall during the crop-growing season was 11.25 inches.

Table IV. Average Monthly and Annual Precipitation by Drainage Districts

Watersheds	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Lake Superior..	0.88	0.88	1.41	2.05	3.50	4.19	4.21	3.73	4.18	2.80	1.45	1.13	30.40
Rainy River....	0.94	0.94	1.42	1.96	3.10	4.04	3.76	3.32	2.98	2.08	1.46	0.98	26.98
Red River.....	0.55	0.56	0.98	1.84	2.85	3.83	3.34	3.12	2.32	1.55	0.72	0.56	22.22
Mississippi (above St. Croix)....	0.73	0.70	1.23	2.16	3.42	4.13	3.61	3.57	3.00	2.29	1.05	0.73	26.63
St. Croix and Mississippi (below St. Croix)....	0.92	0.95	1.49	2.37	4.01	4.46	3.72	3.69	3.72	2.73	1.36	1.13	30.57
Minnesota River	0.79	0.73	1.19	2.30	3.52	4.18	3.34	3.44	2.63	2.11	1.02	0.79	26.04
Big Sioux and Des Moines Rivers	0.50	0.54	1.13	2.09	4.00	4.39	3.49	3.58	2.79	2.07	0.94	0.63	26.15
State.......	0.76	0.75	1.25	2.18	3.53	4.19	3.55	3.50	3.02	2.24	1.09	0.84	26.90

June is the wettest month with an average rainfall of 4.18 inches, and July is next with 3.79 inches. The lowest monthly rainfall is that of February with an average of 0.66 inch. The greatest rainfall in one month for the state as a whole was 8.34 inches in June, 1914. The lowest rainfall for any month was .05 inch in December, 1913.

The geographic distribution of annual and monthly precipitation is

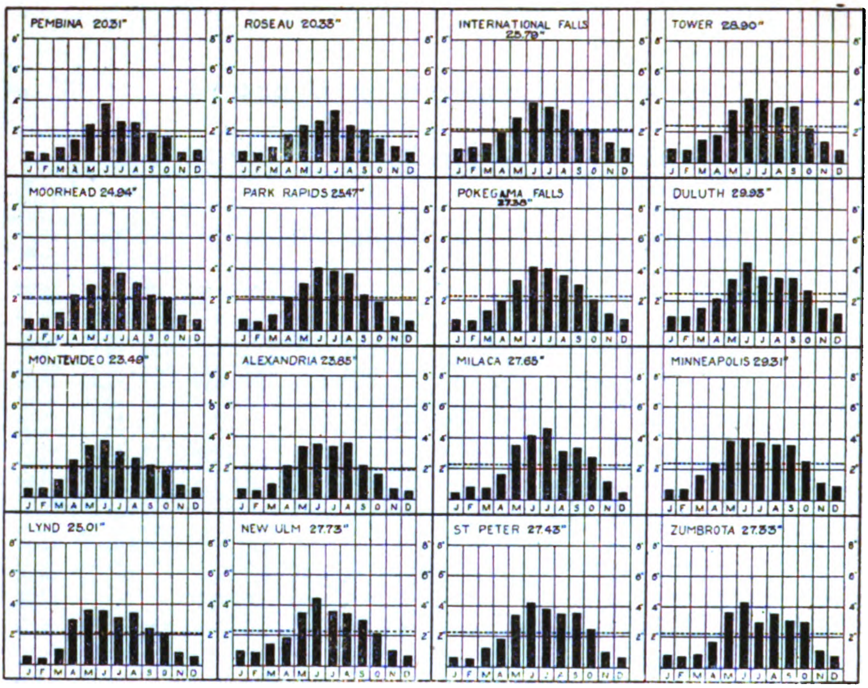


FIGURE 13. DIAGRAM SHOWING COMPARATIVE MONTHLY DISTRIBUTION OF PRECIPITATION IN MINNESOTA. LETTERS INDICATE MONTHS, BLACK COLUMNS INDICATE INCHES OF RAINFALL IN EACH MONTH AT STATION NAMED

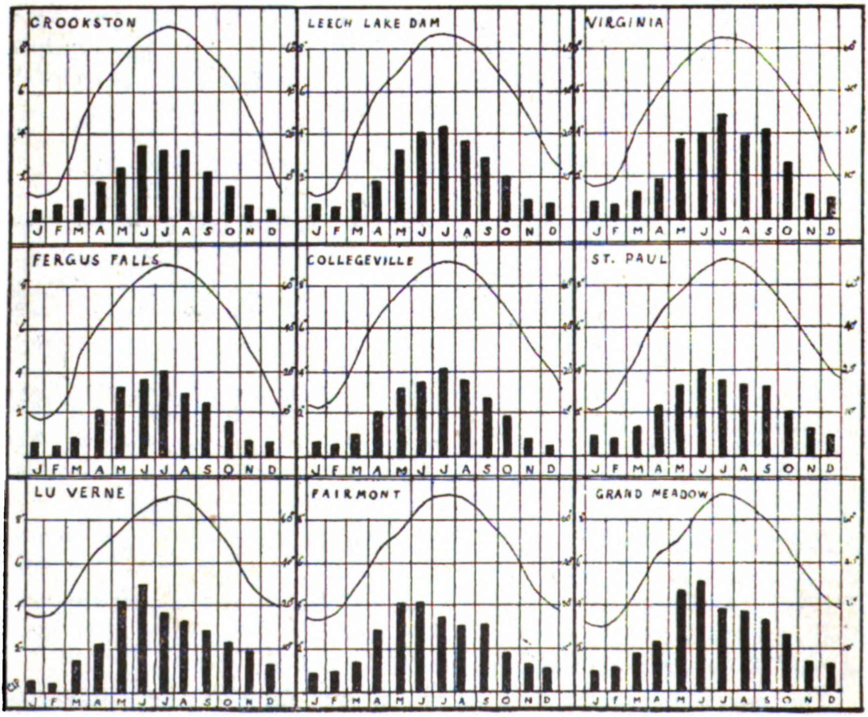
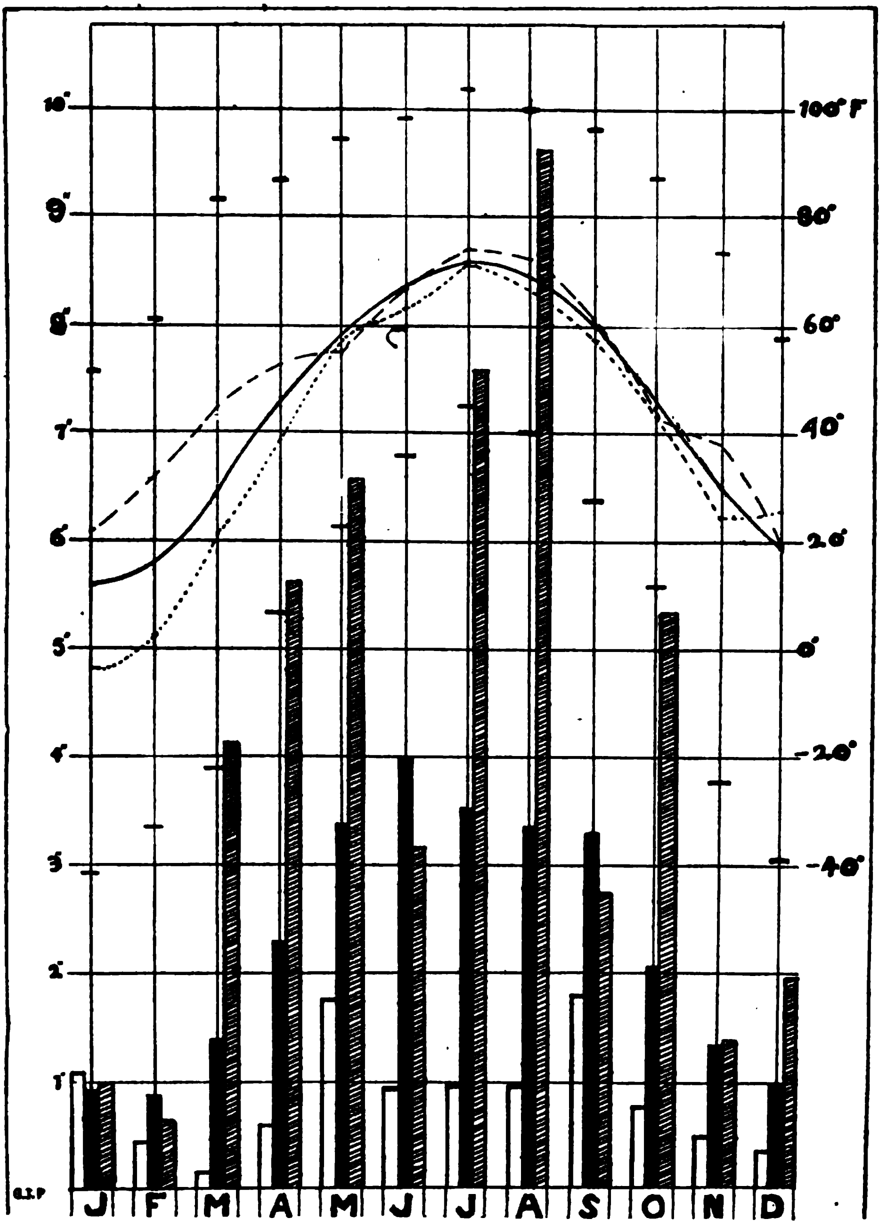


FIGURE 14. DIAGRAM SHOWING MEAN MONTHLY RAINFALL AND MEAN MONTHLY TEMPERATURE AT SEVERAL STATIONS IN MINNESOTA. MONTHS ARE INDICATED BY THEIR FIRST LETTERS. THE GREATEST RAINFALL IS IN THE GROWING SEASON.



■ =mean monthly rainfall, 1873-1913.
■ =monthly rainfall of year of greatest rainfall recorded, 1849.
□ =monthly rainfall of year of least rainfall recorded, 1910.
Solid curve=mean monthly temperature, 1871-1913.
Dotted curve=mean monthly temperature for year of lowest annual temperature recorded, 1875.
Dashed curve=mean monthly temperature for year of highest annual temperature recorded, 1878.
Horizontal dashes show absolute maximum and minimum temperatures recorded.

FIGURE 15. DIAGRAM SHOWING RAINFALL AND TEMPERATURES (DEGREES FAHRENHEIT) AT ST. PAUL, MINNESOTA FROM 1837-1913. MONTHS ARE INDICATED BY THEIR FIRST LETTERS

graphically shown in Figures 12 to 14, and for the stations having ten or more years of record in Table V. Table IV shows the monthly and annual distribution in the various watersheds. From these illustrations it may be seen that the precipitation is about one-fourth to one-third greater along the eastern boundary of the state than along the western boundary.

Table V. Average Annual Precipitation in Minnesota by Stations

Stations	County	Length of record	Average annual precip.	Station	County	Length of record	Average annual precip.
		Yrs.	Inches			Yrs.	Inches
Albert Lea	Freeborn	21	29.90	Montevideo	Chippewa	22	23.50
Alexandria	Douglas	25	23.74	Moorhead	Clay	31	24.92
Angus	Polk	10	19.00	Morris	Stevens	27	23.23
Ashby	Grant	14	24.47	New London	Kandiyohi	18	23.62
Beardsley	Bigstone	16	23.79	New Richland	Waseca	10	29.91
Bird Island	Renville	22	24.23	New Ulm	Brown	32	27.74
Blooming Prairie	Steele	13	27.45	Northfield	Rice	12	29.92
Caledonia	Houston	19	33.70	Osceola, Wis.	Polk	21	32.13
Collegeville	Stearns	19	22.76	Park Rapids	Hubbard	22	25.71
Crookston	Polk	22	22.41	Pembina, N. D.	Pembina	14	19.79
Detroit	Becker	16	25.96	Pine River Dam	Crow Wing	25	27.52
Duluth	St. Louis	41	29.93	Pipestone	Pipestone	12	24.18
Fairmont (near)	Martin	25	28.20	Pokegama Falls	Itasca	25	27.62
Faribault	Rice	14	28.00	Red Wing	Goodhue	16	31.71
Farmington	Dakota	24	29.29	Redwood Falls	Redwood	13	24.65
Fergus Falls	Otter Tail	24	23.24	Reeds Landing	Wabasha	16	29.31
Flandreau, S. D.	Moody	22	24.57	St. Charles	Winona	21	30.68
Fort Ripley	Crow Wing	43	25.25	St. Cloud	Sherburne	19	27.68
Glencoe	McLeod	15	26.64	St. Paul	Ramsey	41	28.68
Grand Meadow	Mower	24	32.59	St. Peter	Nicollet	18	27.89
Grantsburg, Wis.	Burnett	21	33.06	Sandy Lake Dam	Aitkin	19	26.47
Hallock	Kittson	13	21.37	Shakopee	Scott	15	28.85
Halstad (Ada)	Norman	16	21.27	Tonka	Hennepin	13	30.54
International Falls	Koochiching	10	25.75	Tower (Ely)	St. Louis	10	28.17
La Crosse, Wis.	La Crosse	40	31.17	Two Harbors	Lake	18	30.56
Leech Lake Dam	Cass	24	27.00	University, N. D.	Grand Forks	20	20.47
Long Prairie	Todd	20	25.17	Virginia (Mt. Iron)	St. Louis	18	30.74
Luverne	Rock	15	27.60	Wabasha	Wabasha	17	30.54
Lynd	Lyon	19	25.43	Wahpeton, N. D.	Richland	20	23.67
Mankato	Blue Earth	14	27.50	Willmar	Kandiyohi	10	25.54
Mapleplain	Hennepin	17	31.11	Willow River	Pine	10	29.98
Milaca	Mille Lacs	13	27.27	Winnebago	Faribault	14	30.58
Milan	Chippewa	18	24.49	Winnibigoshish	Itasca	25	25.66
Milbank, S. D.	Grant	21	22.69	Winona	Winona	16	29.63
Minneapolis	Hennepin	21	29.31	Worthington	Nobles	17	28.24

Figure 14 makes an interesting comparison of monthly and annual values of both temperature and rainfall at certain selected representative stations.

Snowfall.—The snowfall averages from 24 to 54 inches. It is lightest in the southwest portion of the state and heaviest on the Mesabi Iron Range. The monthly and annual averages are shown in Table VI, arranged according to sections and drainage districts.

Winds.—The prevailing winds are from the northwest over most of the state. The monthly and annual prevailing directions are shown for a large group of stations in Table VII. The average hourly wind velocity is shown for six regular Weather Bureau stations and three special stations in Table VIII.

Relative humidity.—The average annual humidity for the state is

Table VI. Average Snowfall

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
	Yrs.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Lake of the Woods Group—														
Rea River Valley Group—							0	0	0	0.2	0.4	8.4	8.2	50.5
Tower	9	9.0	8.6	10.9	4.2	0.6								
St. Vincent-Pembina	14	8.4	5.1	6.9	5.2	0.7	0	0	0	0.1	0.7	5.7	6.4	39.2
Crookston	14	6.3	6.7	8.8	3.2	2.0	0	0	0	T.	0.4	4.5	5.7	35.8
Moorhead	17	7.6	6.7	8.9	4.9	0.3	0	0	0	0.1	1.0	6.9	6.8	43.7
Upper Mississippi River Valley Group—														
Park Rapids	14	9.0	6.5	9.1	5.4	0.9	0	0	0	0.2	1.4	7.4	6.3	46.2
Lake Winnibigosish	14	8.6	6.5	9.9	3.3	0.8	0	0	0	T.	1.0	7.8	7.8	45.7
Sandy Lake Dam	14	9.0	9.5	10.6	3.6	0.7	0	0	0	0.2	1.1	7.4	7.4	49.4
Lake Superior Group—														
Mt. Iron	13	9.9	7.8	11.2	3.9	1.1	0	0	0	0.1	0.8	8.1	11.6	54.4
Duluth	25	10.3	9.1	11.1	4.0	1.0	0	0	0	0.1	0.3	8.2	8.7	52.8
Lower Mississippi River Valley Group—														
La Crosse, Wis.	15	8.4	8.7	6.6	1.4	T.	0	0	0	T.	0.1	3.9	8.9	37.1
Grand Meadow	14	8.0	9.8	9.9	3.1	0.4	0	0	0	T.	0.3	5.3	9.3	46.1
St. Charles	9	7.7	9.4	9.5	2.4	0.2	0	0	0	0	0.1	4.3	9.3	42.9
Red Wing	8	8.0	5.6	4.4	1.8	0.2	0	0	0	T.	0.3	1.5	7.1	28.9
St. Paul	24	7.7	6.2	8.8	3.6	0.2	0	0	0	T.	0.2	4.7	5.7	37.1
Lower Minnesota River Valley Group—														
Shakopee	14	7.7	8.1	7.8	1.9	T.	0	0	0	T.	0.4	3.0	4.6	33.5
St. Peter	13	5.5	6.1	7.1	0.7	T.	0	0	0	0	0.4	1.4	4.0	25.2
Winnebago	10	6.5	7.5	6.3	1.0	T	0	0	0	T.	0.3	2.3	6.5	30.4
Middle Mississippi River and St. Croix Valleys Group—														
Minneapolis	18	8.3	8.6	9.5	4.0	0.2	0	0	0	T.	0.3	4.5	6.4	42.4
Collegeville	14	6.7	5.6	8.5	1.8	0.4	0	0	0	T.	0.3	3.5	5.0	31.8
Pine River Dam	14	9.1	8.4	9.5	2.8	2.8	0	0	0	0.1	0.6	5.9	6.8	44.0
Osceola, Wis	11	9.1	8.4	11.7	2.8	T.	0	0	0	T.	0.1	5.5	6.8	44.4
Grantsburg, Wis.	11	9.2	9.0	12.2	4.2	0.1	0	0	0	0	0.1	8.5	8.9	52.2
Upper Minnesota River Valley Group—														
New Ulm	14	8.9	7.5	9.5	1.7	0.2	0	0	0	T.	0.3	3.5	4.4	36.0
Bird Island	14	4.7	5.8	6.0	1.5	0.4	0	0	0	T.	0.5	3.5	3.4	25.8
Milan	14	7.5	8.1	11.2	1.6	0.5	0	0	0	T.	0.6	4.1	6.1	39.7
Minnesota River Watershed Group—														
New London	14	4.6	4.2	7.0	1.7	0.1	0	0	0	0	0.3	2.7	3.4	24.0
Long Prairie	14	5.7	5.5	7.4	2.4	0.4	0	0	0	T.	0.2	3.3	4.4	29.3
Morris	14	5.2	5.4	7.8	2.1	0.5	0	0	0	0	0.6	3.2	4.4	29.2
Fergus Falls	13	6.2	5.7	7.6	2.8	0.4	0	0	0	T.	1.0	5.7	5.8	35.2
Southwestern Group—														
Fairmont	13	5.0	10.0	8.8	1.9	0.1	0	0	0	T.	0.2	3.9	5.3	35.2
Worthington	13	4.1	7.2	7.6	1.2	T.	0	0	0	0	0.3	2.7	3.6	26.7
Lynd	14	6.3	5.1	7.4	2.8	0.5	0	0	0	T.	1.2	2.8	5.3	31.4
Gary, S. D.	11	4.4	6.6	12.4	4.5	0.2	0	0	0	T.	1.2	4.2	4.1	37.6

83 per cent at 7 a.m. and 72 per cent at 7 p.m. Table IX gives the monthly and annual data.

Number of rainy days.—In Table X the number of rainy days during each month and the year is given for thirty-three stations well distributed over the state. The smallest number is 64 at Lynd, Lyon County, and the largest 132 days at Duluth.

Sunshine.—The sunshine is abundant, averaging from 43 to 53 per cent of the highest amount possible. The daylight hours are materially longer during the crop-growing season in the northern portion of the state than in the southern. The greatest percentage of sunshine is in the southwestern portion and the least in the northeastern part.

Table VII. Prevailing Wind Direction

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Year
Lake of the Woods Group—														
Tower	9	nw.	w.	nw.	w.	w.	w.	w.	w.	w.	w.	w.	nw.	w.
Red River Valley Group—														
St. Vincent-Pembina	23	nw.	nw.	nw.	nw.	nw.	se.	s.	se.	nw.	nw.	nw.	nw.	nw.
Crookston	14	s.	nw.	s.	n.	nw.	s.	sw.	se.	nw.	s.	s.	nw.	s.
Moorhead	28	nw.	nw.	nw.	n.	n.	se.	s.	se.	se.	se.	nw.	nw.	n.
Upper Mississippi River Valley Group—														
Park Rapids	16	nw.	nw.	nw.	nw.	s.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw
Lake Winnibigoshish	16	nw.	nw.	w.	nw.	nw.	w.	w.	w.	w.	nw.	nw.	nw.	nw.
Sandy Lake Dam	14	nw.	nw.	nw.	se.	e.	e.	nw.	nw.	s.	nw.	nw.	nw.	nw.
Lake Superior Group—														
Mt. Iron	14	nw.	n.	n.	n.	n.	s.	s.	n.	s.	s.	nw.	nw.	n.
Duluth	38	sw.	nw.	ne.	ne.	ne.	ne.	ne.	ne.	ne.	ne.	sw.	sw.	ne.
Lower Mississippi River Valley Group—														
La Crosse, Wis.	36	s.	s.	n.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
Grand Meadow	15	nw.	nw.	nw.	nw.	nw.	se.	s.	s.	s.	sw.	nw.	nw.	nw.
St. Charles	13	nw.	nw.	se.	se.	nw.	se.	se.	nw.	s.	se.	nw.	nw.	nw.
Red Wing	12	nw.	nw.	nw.	se.	e.	se.	sw.	w.	e.	w.	nw.	nw.	nw.
St. Paul	38	nw.	nw.	nw.	nw.	se.	se.	se.	se.	se.	se.	nw.	nw.	se.
Lower Minnesota River Valley Group—														
Shakopee	14	nw.	nw.	nw.	se.	se.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
St. Peter	13	nw.	nw.	nw.	nw.	nw.	nw.	se.	nw.	s.	nw.	nw.	nw.	nw.
Winnebago	9	nw.	nw.	nw.	nw:	se.	se.	se.	se.	se.	se.	nw.	nw.	nw.
Middle Mississippi River and St. Croix Valleys Group—														
Minneapolis	18	nw.	nw.	nw.	nw.	ne.	s.	s.	s.	s.	s.	nw.	nw.	nw.
Collegeville	14	nw.	nw.	nw.	s.	nw.	sw.	s.	nw.	s.	nw.	nw.	nw.	nw.
Pine River Dam	16	nw.	nw.	nw.	nw.	nw.	w.	w.	nw.	nw.	nw.	nw.	nw.	nw.
Osceola, Wis.	11	s.	s.	n.	n.	s.	s.	s.	s.	s.	n.	n.	s.	s.
Grantsburg, Wis.	11	nw.	nw.	sw.	se.	ne.	sw.	sw.	sw.	sw.	nw.	nw.	nw.	nw.
Upper Minnesota River Valley Group—														
New Ulm	14	nw.	nw.	s.	s.	s.	s.	s.	s.	nw.	nw.	nw.	nw.	nw.
Bird Island	16	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
Milan	14	nw.	nw.	nw.	se.	se.	se.	nw	se.	nw.	nw.	nw.	nw.	nw.
Minnesota River Watershed Group—														
New London	14	nw.	nw.	nw.	se.	se.	se.	se.	se.	se.	se.	nw.	nw.	se.
Long Prairie	14	nw.	nw.	nw.	se.	se.	nw.	nw.	se.	se.	nw.	nw.	nw.	nw.
Morris	17	nw.	nw.	s.	s.	s.	s.	s.	s.	s.	s.	n.	s.	s.
Fergus Falls	13	nw.	nw.	nw.	se.	se.	se.	nw.	se.	nw.	nw.	nw.	nw.	nw.
Southwestern Group—														
Fairmont	15	nw.	nw.	nw.	nw.	nw.	s.	s.	nw.	s.	nw.	nw.	nw.	nw.
Worthington	13	nw.	nw.	nw.	s.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
Lynd	14	nw.	nw.	nw.	nw.	se.	nw.	sw.	nw.	nw.	sw.	nw.	nw.	nw.
Gary, S. D.	11	nw.	nw.	nw.	sw.	se.	se.	se.	s	ne.	sw.	nw.	nw.	nw.

Table VIII. Average Hourly Wind Velocity in Miles

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Duluth	5	14.3	14.2	15.0	15.1	15.2	11.6	11.3	12.0	12.7	13.9	14.1	14.2	13.6
Moorhead	19	10.3	10.5	11.3	12.0	10.7	10.0	8.3	8.4	10.4	10.4	10.1	10.0	10.2
St.Vinc'nt-Pembina	15	7.7	9.4	10.0	10.7	10.0	8.7	7.5	7.5	9.1	9.3	9.5	8.9	9.2
Two Harbors	6	9.0	8.2	9.7	9.4	7.6	7.4	7.3	7.2	8.0	8.3	8.7	8.9	8.3
La Crosse, Wis.	36	7.1	7.5	8.0	8.5	7.5	6.7	6.0	5.8	6.9	7.5	7.5	7.2	7.2
St. Paul	36	7.8	8.3	8.8	9.3	8.7	7.7	7.1	7.1	8.0	8.5	8.1	7.8	8.1
Minneapolis	18	11.5	11.6	12.3	12.8	12.1	10.3	9.9	9.9	11.6	11.7	11.0	11.2	11.3
Faribault	7	9.4	9.1	9.4	11.0	9.0	7.3	5.9	6.4	7.8	8.8	9.0	9.1	8.5
Collegeville	11	9.5	9.6	11.0	12.2	11.1	10.0	9.4	9.4	10.9	9.5	9.9	9.9	10.2

Table IX. Mean Relative Humidity in Degrees

Stations		Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Duluth	8 a.m.	21	83	83	81	76	76	79	79	81	82	81	83	84	81
	8 p.m.	21	77	75	71	65	64	69	65	69	71	72	76	78	71
Moorhead	8 a.m.	21	89	88	88	84	79	84	86	87	87	84	89	89	86
	8 p.m.	21	86	86	82	65	56	62	64	61	63	69	81	85	72
St. Vincent	8 a.m.	4	80	80	88	88	79	84	88	90	87	89	89	87	86
	8 p.m.	4	83	86	88	77	58	66	71	70	71	78	89	89	77
La Crosse, Wis.	8 a.m.	21	83	82	79	74	75	79	81	85	85	81	81	83	81
St. Paul	8 a.m.	21	84	84	81	75	75	79	79	83	83	81	81	83	81
	8 p.m.	21	76	75	68	55	54	58	55	56	60	63	69	76	64
Minneapolis	8 p.m.	7	83	79	76	66	66	67	65	68	72	73	79	83	74

Table X. Number of Days with 0.01 Inch or More of Precipitation

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Lake of the Woods Group—														
Tower	9	5	4	6	5	8	9	10	8	10	7	5	5	82
Red River Valley Group—														
St. Vincent-Pembina	25	7	6	7	7	8	11	10	9	8	7	7	7	94
Crookston	14	4	4	5	6	8	10	8	8	6	5	3	4	71
Moorhead	28	8	9	8	9	11	12	10	9	8	8	7	8	107
Upper Mississippi River Valley Group—														
Park Rapids	14	8	7	10	9	11	13	11	10	9	9	7	8	112
Lake Winnibigoshish	15	6	4	7	6	10	10	9	8	7	5	5	6	83
Sandy Lake Dam	14	6	6	8	6	10	10	10	10	9	8	6	6	95
Lake Superior Group—														
Mt. Iron	14	5	4	5	5	9	11	10	9	9	7	5	6	85
Duluth	38	10	9	10	9	12	14	12	12	12	10	11	11	132
Lower Mississippi River Valley Group—														
La Crosse, Wis.	36	10	8	10	10	12	12	10	9	10	9	8	10	120
Grand Meadow	15	6	5	7	7	12	9	9	8	8	7	6	6	90
St. Charles	12	5	4	6	6	9	11	7	6	8	7	5	4	78
Red Wing	10	5	5	6	7	11	10	7	7	8	6	5	5	82
St. Paul	38	9	8	10	10	12	12	10	10	9	9	8	9	114
Lower Minnesota River Valley Group—														
Shakopee	14	5	5	7	8	11	10	9	9	9	8	6	5	92
St. Peter	12	3	3	5	6	10	9	7	7	6	5	3	2	66
Winnebago	10	4	4	6	6	12	11	9	9	7	7	3	4	82
Middle Mississippi River and St. Croix Valleys Group—														
Minneapolis	18	8	7	9	9	12	12	9	9	8	9	7	8	107
Collegeville	14	6	5	8	7	10	12	10	10	9	8	6	5	96
Pine River Dam	15	4	4	6	6	9	10	8	8	7	6	4	4	76
Osceola, Wis.	11	7	5	6	6	8	9	8	7	6	7	5	5	79
Grantsburg, Wis.	11	5	4	5	6	8	7	7	6	5	4	5	6	68
Upper Minnesota River Valley Group—														
New Ulm	14	5	5	7	7	11	11	8	8	8	7	5	4	86
Bird Island	14	4	3	6	7	10	10	8	8	8	6	5	3	78
Milan	14	6	5	7	7	9	11	8	8	7	6	5	5	84
Minnesota River Watershed Group—														
New London	14	3	3	5	5	9	9	7	6	6	5	4	3	65
Long Prairie	14	4	4	6	8	10	11	8	8	8	7	5	3	82
Morris	16	4	4	6	7	11	12	9	9	7	6	4	4	83
Fergus Falls	13	11	8	11	9	12	15	11	11	10	8	7	10	123
Southwestern Group—														
Fairmont	15	4	4	5	6	10	8	7	7	7	5	3	3	69
Worthington	13	4	4	4	6	11	10	14	8	6	5	4	4	80
Lynd	14	3	3	5	5	8	9	7	8	6	4	3	3	64
Gary, S. D.	11	3	2	3	5	6	5	6	5	4	4	3	1	47

The precipitation in the area embraced in the present report, as shown in Figure 12, increases from northwest to southeast, being about 25 inches in the northwest part and over 32 inches in the southeast. Although there is an increase on approaching Lake Superior the influence of the lake in increasing precipitation near its shore seems to be very slight, for in parts of Minnesota farther south where there is no lake influence a similar increase in the amount of precipitation is found in passing from northwest to southeast.

CHAPTER III

AGRICULTURAL CONDITIONS AND LAND CLASSIFICATION IN THE NORTHEAST QUARTER OF MINNESOTA

GENERAL STATEMENT

The northeast quarter of Minnesota lies within the area of mixed coniferous and deciduous forests (Figure 3), and was heavily wooded, except in some of the muskeg swamps, and in narrow marshy strips bordering lakes and streams. The sandy and loose-textured soils are occupied largely by pine forests, while the clayey or heavier classes of soil carry usually a mixed growth, embracing deciduous as well as coniferous trees.

Agricultural development is as yet very limited in all parts of this area. In most localities farming has begun within the past ten or fifteen years. The clearing of stumps, draining of swamps, and opening of roads, each require much labor and thus retard a rapid agricultural development. The region is, however, sufficiently well watered, and large areas of it have a soil productive enough to give adequate returns for the expenditure of labor required to bring the land under cultivation. This region is not affected by drouths in late summer such as often cut short the pasturage in districts farther south and west. Very little feeding is, therefore, required until the pastures become snow-covered.

Railway facilities are good in Carlton and much of Aitkin County and over the territory lying between the Mesabi Iron Range and Lake Superior. Koochiching County also has fair railway advantages. There is urgent need for a railway leading northeastward from Duluth through Lake and Cook counties. At present the Minnesota and Northeastern, used largely for lumbering operations, furnishes an outlet for southern Lake County. Boat service is maintained along the shore of Lake Superior from May 1 to November 30, thus furnishing an outlet for the produce of Cook as well as Lake County.

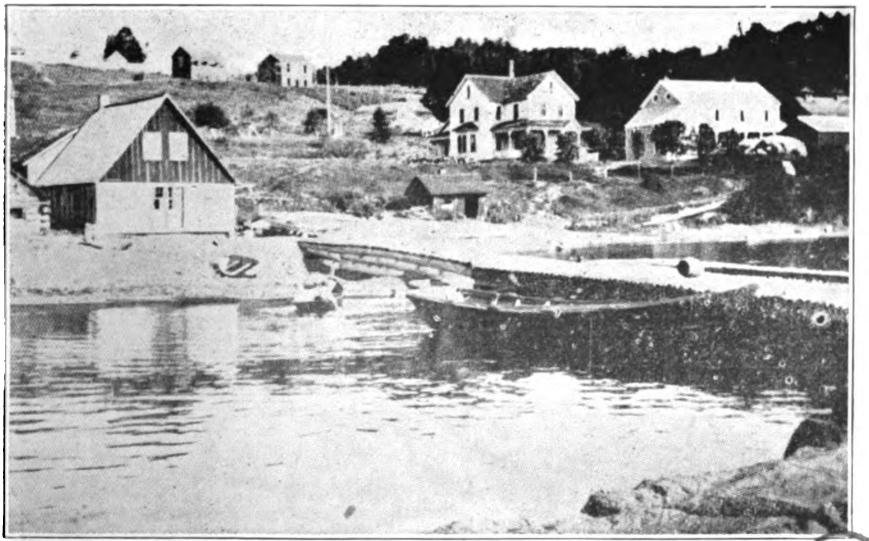
The larger part of the population of this northeast quarter of Minnesota is along the shore of Lake Superior and the mining towns on the iron ranges and in villages scattered along the railways. Not more than twenty per cent of the population are engaged in agricultural pursuits. Of this population a considerable part combine other pursuits with farming and are employed part of their time in the cities or in logging camps. Year by year, however, a larger percentage of the farmers are giving their entire time to farm development.

The three counties north of Lake Superior each have large areas with rock hills which carry only a scanty cover of drift. The scanty soil combined with the steepness of slope renders them of little or no agricultural value. These rocky lands are largely embraced in the National Forest and yield better returns from their forests than could be obtained by farming them. These three counties have, however, certain advantages, because of their frontage on Lake Superior. A narrow strip along the lake shore should become a profitable one for the growing of vegetables and even of hardy fruits, which can be readily marketed by boats running to Duluth. The loose-textured soil of this belt also adapts it for the growth of garden truck.

Swamps are numerous in every county in the northeast quarter of the state, and there are extensive muskegs in western St. Louis, Koochiching, and Aitkin counties. The drainage surveys have shown, however, that in the largest swamps as well as in the smaller ones the surface slope is generally sufficient to insure effective drainage. The soil of the swamps also is generally of such a nature as to be very productive when drained. The water courses which have developed in and near these swamps by natural drainage have in most cases channels of sufficient capacity to carry off all water which would be discharged into them from the ditches necessary to drain the swamp areas. A considerable improvement in the drainage and reduction of the area of swamp lands may easily be effected by removing obstructions from the natural water courses, such as old beaver dams and the fallen timber and other obstructing material. Such obstructions are found in nearly all of the small stream channels throughout the area. Large areas of these swamp lands are held by the State, and many projects for their reclamation have been worked out by the State Drainage Engineer and embodied in his report for 1906.

There are wide differences in the character of the glacial deposits in northeastern Minnesota. The cause of some of these differences was the peculiar relations of the deposits to the melting ice, and some were caused by differences in the rock material contained in the drift. Drift laid down under the ice naturally contains a considerable amount of fine clayey or loamy material along with the coarser rock constituents. But drift laid down at the edge of the ice has in places had the fine material largely removed by the waters discharging from the ice border, and the coarse material is thus concentrated into beds of gravel and cobble. There are places, however, where lakes were held between the ice and the higher country outside, or in regions where the escape of the water was inadequate. In such places a fine sediment was laid down outside the ice on the beds of the lakes or ponded waters.

A. GARDEN PLOT OF ANTHONY GASCO ON LAKE HARRIET, LAKE COUNTY
PHOTO BY A. H. ELFTMAN



B. FARM ON SHORE OF LAKE SUPERIOR AT LUTZEN, COOK COUNTY
TERRACING MARKS HIGHER LAKE LEVELS

UNIV. OF MICH.

The temporary Lake Aitkin, which occupied the district traversed by the Mississippi in its course through Aitkin County, deposited a fine and highly productive sediment over much of its bed. The flat land in the St. Louis basin, covered by Lake Upham, now carries deposits of fine sand and silt over a wide area in western St. Louis and northeastern Aitkin County. It embraces the extensive muskeg swamps of that region.

On the bed of Lake Duluth, at its southwest end, in Carlton County and neighboring parts of Wisconsin, there is considerable clay, but in a narrow strip exposed on the north side of Lake Superior there has been in places a removal of the fine material and a concentration of coarse material in the bars and beaches of the lake.

Lake Agassiz extended from the Red River basin and plains of Manitoba as far east as the northwest part of the area herein described (Plate I). All of Koochiching County except a strip two to eight miles wide on its southern border was covered by this lake. It also covered about twenty townships in the northwest part of St. Louis County. The part in Koochiching County has a nearly plane surface and a considerable deposit of fine lake sediment except on the immediate borders of Rainy Lake and small areas in the southeast part of the county where rock knobs are exposed. The lake deposits with heavy soil extend up Little Fork valley into St. Louis County and are found in narrow lowland strips among the rock hills in northwestern St. Louis County. The greater part of this lake area inside the limits of St. Louis County, however, has a rocky surface much of which was swept bare by the action of the lake waves, and thus rendered of little value for agriculture.

The kind of rock material contained in the drift depends to some extent upon the direction from which the ice invaded this region. As already indicated the studies of the deposits have brought out the interesting fact that the ice invasions came from three directions, the northwest, the north, and the east. The invasion from the northwest was by ice which covered much of Manitoba and spread over a great part of northern Minnesota. It brought in deposits of drift containing large amounts of limestone which the ice had gathered in its passage across limestone formations in Manitoba. This is known as the Keewatin drift, since the ice started from the region formerly called the Keewatin district of central Canada (but now largely included in Manitoba). It is also known as the gray drift, this term having been applied by Winchell and his associates in their reports in the Minnesota Geological Survey. The color is gray, however, only in the unoxidized portions, and the surface of the drift, that has been oxidized, has a brown color. There are also places in the vicinity of the Mesabi Iron Range, where on account of the introduction of reddish material from the iron formations, it all presents a red color. The color name, therefore, becomes rather confusing when one attempts to apply it widely. For this reason the term Keewatin drift is used in the present report.

The border of the Keewatin drift is indicated on Plate I and also on Figure 2. On the northeast it lies only a few miles south of the Canadian line from the mouth of Rainy Lake eastward to Nameokan Lake in St. Louis County. It then leads southward to the west end of Vermilion Lake. Then after a slight eastward turn in the Little Fork drainage basin it swings southward and comes to the Mesabi Iron Range near Chisholm. But the high part of the range from there westward about to the Itasca County line seems to have stood above its limits. On passing over the range into the basin south of it the Keewatin ice spread out widely over the St. Louis drainage basin and also down the Mississippi to the edge of Crow Wing County. The southwest limits run through northwestern Aitkin County and thence westward across Cass County to the south of Leech Lake, passing beyond the limits of the area under discussion. In the district covered by the Keewatin drift the glacial deposits are exceptionally rich and of a less stony character than in districts to the east and south which were covered by drifts derived from other sources.

Ice invaded the northeast part of Minnesota also partly by a westward movement of the Labrador ice sheet through the Superior basin and partly by a southward movement from the district of Patricia in the neighboring part of Canada. A part of the drift deposited by these invasions is called the Superior drift and the other part the Patrician drift. Both of these drifts have a reddish color owing to the large amount of red rock material incorporated in them, and they embrace what is termed the red drift of Minnesota in the reports of the Winchell Survey.

The relations of the Patrician ice movement to the Superior and Keewatin ice movements are somewhat complex. The Patrician movement extended over eastern Minnesota southward a little beyond St. Paul into Scott and Dakota counties, and covered at least one third of the state. It is found to have done so before the movements from the Keewatin and Superior ice fields had reached into northeastern Minnesota, for territory which it occupied was later invaded to some extent by each of these ice fields, and the deposits of the Patrician ice are overlain by the Keewatin and Superior drifts in such regions of overlap. The borders of the drift of the Superior and of the Keewatin ice approach each other closely for a few miles in southwestern St. Louis and northwestern Carlton and the eastern edge of Aitkin County, and the Patrician drift is there found beneath one or the other of them. (See Plate II A and II B). Farther south in Aitkin and neighboring counties, as shown in

A. SHORES AND ISLANDS OF VERMILION LAKE

B. CROSS RIVER MEANDERING THROUGH A SPRUCE SWAMP IN ITS HEADWATERS

Figure 2, the Patrician drift is at the surface. It is also at the surface at the northeast in St. Louis, Lake, and Cook counties between the drift of the Keewatin ice field and that of the Superior lobe of the Labrador ice field. The precise relations of the Superior lobe and Patrician ice in the district north of Lake Superior will be taken up in the discussion of Lake County. Attention is accordingly directed here only to the differences in the character of their drifts.

In the drift brought in by the Superior lobe there is on the whole a large proportion of loamy material in which the coarse crystalline rocks are imbedded. The soil is what might appropriately be termed stony loam. It becomes more gravelly on its northwest edge in the headwaters of Cloquet River because of the discharge of water there along the ice border. The drift deposited by the Patrician ice is generally very stony because of the derivation of its material from the crystalline rock formations over which the ice passed, and which do not readily break down into clayey material. The contrast between it and the drift of the Superior lobe is, however, less striking than between it and the drift of the Keewatin ice sheet, and there are places where the drift of the Superior lobe is fully as stony as that from the Patrician ice. The larger amount of loam in the Superior drift is due in part to the ponded conditions of water along the northwest edge of the Superior ice lobe, there having been ready escape for water along only a part of the border in the headwaters of Cloquet River. It is thought, however, that the formations over which the Superior lobe passed, such as the diabase of Beaver Bay and certain gabbro rocks contributed more material that is easily reduced to clay than did those formations found in the area over which the Patrician ice sheet passed. It was in connection with the retreat of the Superior ice and the Keewatin ice that the glacial lakes, Duluth and Agassiz, noted above were formed.

DESCRIPTIONS OF COUNTIES

In the descriptions of counties which follow the county taken first is in the northeast corner of Minnesota, and after that counties to the west and south to the southern border of the area are discussed. A few data from the census of 1910 are presented in addition to the results of the land classification on a geologic basis.

COOK COUNTY

The recent studies in Cook County were mainly in the part near the shore of Lake Superior where farming has been begun and roads opened. Data concerning the less accessible areas have been obtained from the geological reports of the earlier Geological Survey and from Dr. Arthur

H. Elftman, a member of that survey, who also in 1913 assisted in part of the work in Lake and Cook counties.

Bare rock or rock with a very scanty drift covering occupies about one third of the area of the county, mainly in the north part, and mainly within the limits of the National Forest. But there is also a strip of rugged land known as the "Sawtooth Mountains" which lies near the Superior shore westward from Grand Marais. Several townships in the eastern end of the county are also rugged and thinly covered with drift.

The lakes of Cook County, including those along the Canadian border, are estimated by Mr. George A. Ralph,[1] to cover 274 square miles, while the swamps embrace 135 square miles. Their combined area, 409 square miles, is over one fourth of the county. This, together with the rough and rocky areas, amounts to nearly 60 per cent of the county. Of the remaining 40 per cent a considerable part can not be brought under cultivation except at great expense in clearing of stones and stumps. It may, therefore, prove to be more profitable in forest than under cultivation.

The tracts of heavy drift embrace some moraines, the position and extent of which may be seen by reference to Plate I. Parts of these moraines have a very rough surface with sharp knolls inclosing small swamps. More commonly the glacial deposits are gently undulating with slopes easy to cultivate. The part along the shore which was covered by the waters of Lake Duluth and lower lake stages down to the present Lake Superior, includes numerous gravelly ridges or beaches formed at different levels corresponding to the successive lake levels. The slopes between these gravel ridges have wave-washed drift consisting largely of coarse material. Very little fine sediment was deposited by the lake on this part of the shore. The soil, however, has proved to be productive in the growth of vegetables and cereals.

The prevailing type of soil in the tracts of heavy drift is a stony loam. This is true of moraines, till plains, and of the part within the limits of Lake Duluth. Dr. Elftman reported that there is a strip of heavy drift embraced in flat areas among rock hills on the south side of Pigeon River in Ranges 3, 4, 5, and 6 E. in which a clayey drift is found, which, when cleared and drained, is likely to become valuable agricultural district. It lies partly within the limits of Lake Duluth, but at the west the deposits are somewhat higher than the level of that lake. They may, however, have been laid down in ponded waters along the ice border.

Agricultural development is at present mainly in a narrow strip scarcely five miles wide along the shore of Lake Superior. There is a belt about ten miles wide lying north of the "Sawtooth Mountains" from

---

[1] G. A. Ralph. *Engineer's Report on Topographical and Drainage Survey*, Minnesota, 1906.

Cascade River westward to Temperance River and northward to Brule Lake, in which the drift cover is heavier than to the north. Parts of this may be suitable for agriculture. The roughness of surface, stony character of the drift, and the likelihood of frost in this depression back of the Sawtooth range give the area of thicker drift but little advantage over the rocky area to the north for crop raising, but it should give good returns in forest. The flat areas of heavy drift along Pigeon River, noted above, are also as yet undeveloped, and are likely to remain so until a railway line is constructed which will give an outlet for the produce.

From the census of 1910 it appears that the number of farms had increased in the preceding decade from 36 to 146. Of these, 115 have an area of between 100 and 175 acres, and two have an area over 500 acres. On many there has been very little cultivation of the soil, the average acres of improved land per farm in 1910 being only 10.7. Thus far the market facilities are restricted mainly to the season of boat traffic on Lake Superior which runs from May 1 to November 30. The Minnesota and Northeastern Railroad, however, has now extended its line to the southwest part of the county and thus opened winter connections with Duluth. Vegetables are as yet grown more extensively than cereals but the census returns show that oats, wheat, barley, and rye, have each a good yield per acre.

LAKE COUNTY

In Lake County a strip several miles wide along the shore of Lake Superior in which the principal settlement occurs was examined in detail. Lines of traverse were also carried into the unsettled parts of the county, lumber camps being used as a base from which to work. Dr. Arthur H. Elftman, who joined in part of this investigation, also greatly aided by supplying information concerning the character of soils in several townships in the northern half of the county which he had examined geologically some years previous under the direction of Professor N. H. Winchell. Information concerning the character of land inside the limits of the National Forest was obtained also from the foresters located there.

The northern part of the county, as far south as Tp. 61, is a very broken district with rock knobs among which are lakes and swamps. It carries only a thin coating of glacial drift on the hills, and there is very little easily tillable land. The greater part of this rocky area is included in the National Forest. There are other bare rock ridges in the southern part of Lake County within the limits of the glacial Lake Duluth which owe their bareness in part to the work of the lake waves in removing the drift covering. These rock outcrops are numerous in the southern part of the county for several miles back from the present shore and up to an altitude of 800 to 1,000 feet above the level of Lake Superior. There are several townships lying between these rock ranges and those of the northern half of the county in which the drift is so heavy as to nearly conceal even high rock hills and ridges. There are also flat areas among the exposed rock ranges near the shore of Lake Superior in which heavy deposits of drift occur.

The greater part of Lake County was covered by Patrician ice which came in from the north, there being only a strip fifteen to twenty miles wide next to Lake Superior which was covered by the Superior ice field. Each of these ice fields produced a great system of moraines which become interlocked in the eastern part of Lake County. The system formed by the Patrician ice field leads westward from Tps. 59 and 60 R. 7 W. across this county into St. Louis County, covering much of Tp. 59 R. 8W. and Tp. 60 Rs. 9, 10, and 11W. The several headwater branches of Isabella River start in this morainic system and Stony River has most of its course among its ridges. Between the constituent morainic ridges there are narrow strips of gravel plain formed as outwash from the ice border in the course of the development of the morainic system. The amount of drift in this morainic system is several times as great, square mile for square mile, as in the district to the north of it, in the northern half of Lake County.

A morainic system of the Superior lobe, which joins as a correlative of that of the Patrician ice field just described, leads from their place of junction, which is in Tp. 59, Rs. 7 and 8W, southwestward parallel to the shore of Lake Superior through Lake County into St. Louis County. Its inner border is twelve to fourteen miles from the Lake while the outer border is usually sixteen to eighteen miles. Its position may be seen by reference to Plate I. The highest land areas in Lake County are at the junction of the morainic systems, there being a few knolls on the moraines, which by barometric measurement, exceed 2,000 feet above the sea. Each of the morainic systems descends in passing westward from there to the St. Louis County line to an altitude of about 1,700 feet along their crests. The inner border of the Superior lobe, which is considerably lower than the crest, is, however, generally above 1,500 feet.

In topography the great morainic systems are rough and approach in that respect the rock areas of the northern part of the county, there being numerous hills 50 to 100 feet high with steep sides difficult of cultivation. For this reason settlements in Lake County have thus far avoided these morainic systems.

There are several townships lying between these two great morainic systems in western Lake County which are covered by drift belonging to the Patrician ice movement, the ice having melted there prior to the de-

A. BREAKING GROUND AT MEADOWLANDS

B. STOCK FARM AT MEADOWLANDS

C. FARM PREMISES AT MEADOWLANDS

UNIV. OF MICH.

velopment of the morainic systems. Scattered drift knolls and ridges are found in these townships but they do not appear to form definite morainic belts. The greater part of the surface is nearly plane and much of it is swampy. This district was traversed by lines of glacial drainage which ran away from the great morainic systems toward the southwest. The headwaters of Cloquet and St. Louis rivers are in channels which were developed along those lines by the escape of the glacial waters. The swamps are largely underlaid by sand and gravel deposits brought in by the glacial drainage.

On the slope toward Lake Superior there are narrow strips of moraine developed as the ice border halted in its retreat into the Superior basin. They are far less conspicuous, however, than the great morainic systems above noted.

From the junction of the two great morainic systems in T. 59, R. 7W. northeastward into Cook County where the two ice fields were coalesced they did not form moraines. Instead, the ice fields appear to have blocked each other's movements almost completely and to have become ramified near their junction by tunnels through which the water formed by the melting of the ice flowed and deposited gravel and sand in the tunnels. After the ice was all melted these deposits of gravel and sand settled down on the underlying drift-covered surface, and remained there as steep sided gravel ridges called eskers. In Plate IV A one of these ridges which is 90 feet high is shown and it will be noted that the crest is barely wide enough for a wagon track. Eskers are found quite commonly in the glaciated districts. In this locality they are found at the junction of two ice fields but such eskers occur frequently inside the area of a single ice field. They formed when ice movement had practically ceased and where the ice had become ramified by tunnels. Eskers furnish good material for road building rather than good soil. They are of great value for road material, especially in districts where there is a clayey drift.

The waters of Lake Duluth are found to have extended back to a distance of four or five miles from the present shore of Lake Superior in the region from Knife River as far northeast as Beaver Bay, though for several miles southwest from Beaver Bay a rock ridge lying back only about two miles from the shore rose slightly above the lake level. From Beaver Bay northeastward the waters of Lake Duluth extended only one and a half to two miles back from the present lake except in narrow inlets in the valleys of Baptism and Manitou rivers. Rocky ridges bordering Lake Superior have greater breadth from Beaver Bay northeastward than they have to the southwest. The beaches of Lake Duluth are ill-defined in these rocky areas but are distinctly seen in the form of definite gravel ridges where the shore was of glacial deposits. These ridges occur at various levels marking the successive lake stages down to the present shore. The highest shore is not far from 550 feet above Lake Superior. It shows a slight rise from southwest to northeast in its course through the county.

The rough areas of rock ridges and hills are estimated to occupy about 40 per cent of the area of Lake County. The lakes occupy about 12 per cent and the swamps, as estimated by the State Drainage Engineer, embrace 297 square miles or 14 per cent of the county. There thus remains only about one third of the area of the county occupied by the better classes of land. Of this a large part is stony loam with numerous cobblestones as well as bowlders in the soil and on the surface. A narrow strip with heavy clay soil and relatively few stones is found along and near the shore of Lake Superior in the southwest part of the county below the level of the highest beach of Lake Duluth. A looser-textured clay loam with only a moderate number of stones included is found above the level of Lake Duluth in Tp. 54, R. 10W., Tp. 55, Rs. 9 and 10W., and Tp. 56, R. 9W. This district is traversed by the Minnesota and Northeastern Railroad, which thus gives it an outlet for the marketing of products. Both of the great morainic systems are very stony but the one formed by the Superior lobe appears to contain somewhat more loam in the soil than that formed by the Patrician ice field. The district lying between these moraines in the western part of Lake County is also very thickly strewn with stony material, except along lines of glacial drainage, where some deposits of gravel and sand occur.

Nearly all the farming settlements in Lake County are in the two areas of clay and clay loam above noted which lie near the Lake Superior shore, and principally within ten miles of it. There are, however, two settlements more remote. One in the western part of the county in the vicinity of Toimi Post Office has a few settlers. The main settlement of about 75 families is in the adjacent part of St. Louis County. Another in Tp. 59, R. 8W. just west of the junction of the two great morainic systems above noted has about 40 settlers. This settlement has the distinction of being the most elevated one in the state, the altitude being between 1,800 and 2,000 feet. Notwithstanding the high altitude, and remoteness from the lake, cereals and vegetables have been grown with marked success. The soil is a stony loam with considerable sandy admixture both in this settlement and the one around Toimi. There are also a few settlers northeast of Ely in Tp. 63, R. 11W., and a few in Tp. 62, R. 10W.

A single farm has been opened on the east shore of Harriet Lake in Tp. 60, R. 6W. by Anthony Gasco, a view of whose premises is given in Plate V A. This farm is at an altitude of nearly 1,800 feet or but slightly lower than that of the settlement in Tp. 59, R. 8W. When visited, on September 15, 1913, there had been no killing frost. Sweet corn, pumpkins, cucumbers, lettuce, turnips, cabbage, beets, tomatoes, and potatoes were all in flourishing condition, as well as cultivated flowers of many kinds. In the year 1912 Mr. Gasco raised $300 worth of garden truck on less than five acres.

The census of 1910 reports only 1.7 per cent of the county, or 34.8 square miles, to be in farms, and only 10.7 per cent of the farm lands to be improved. The crops grown in 1909 were valued at $47,187. Of this $15,659 were for vegetables, and $18,742 for hay and forage. The cereal crop is rated at only $323, there being but 15 acres reported. There has been considerable advance in the development of farms since the census of 1910 was taken, yet it is still true that only a small part of the land that is suitable for cultivation in Lake County has been developed.

ST. LOUIS COUNTY

St. Louis County of which Duluth is the county seat, embraces more than one third of the northeast quarter of Minnesota, its area, according to the Census of 1910, being 6,503 square miles. It extends from the west end of Lake Superior northward to Rainy Lake on the Canadian border, or from T. 48N. to T. 71N., a distance of fully 130 miles. Its north and south ends are irregular, but for 88 miles, from T. 52 to T. 66 inclusive, the county has a regular width of 60 miles. It is traversed by several railway lines radiating from Duluth. Only one of these, the Duluth, Winnipeg and Pacific, extends through to Canada. Several lines have termini in the Mesabi Iron Range.

Nearly all the county is a tableland standing 600 to 900 feet above Lake Superior, or 1,200 to 1,500 feet above sea level. The Mesabi Iron Range and the associated rock ridges rise in places to 1,800 feet above the sea. A prominent moraine in the southeast part of the county is about 1,700 feet where it enters from Lake County, and the bed-rock surface there attains an altitude of about 1,600 feet. The rock surface has an altitude of 1,500 to 1,700 feet along much of the eastern part of the county. The altitude decreases westward in the district on each side of the Mesabi range. That range reaches its highest elevation of about 1,800 feet in the central part of the county.

For a distance of 30 to 35 miles south from the Canadian boundary, or as far south as Pelican, Vermilion, and Birch lakes, the drift is very scanty on the hills and ridges. The Mesabi Range is very thinly coated with drift in places, though its south slope and the portion west from Chisholm carry a relatively heavy coating. Between the Mesabi Range and Vermilion Lake, in the drainage areas of Sturgeon and Little Fork rivers, there is generally a heavy cover of drift. The drift cover is heavy also south of the Mesabi Range, except in a narrow strip fronting on Lake Superior where bare ledges are conspicuous. These ledges are chiefly in T. 49, R. 15W., T. 50, R. 14W., and T. 51, R. 13W. The drift of this county was brought in from the three ice fields discussed in the introductory statement. The Superior ice lobe covered the county from the direction of Lake Superior as far northwest as the valley of Cloquet River. The Keewatin ice field extended into the county from the northwest covering about twenty townships north of the Mesabi Iron Range, and a still larger area in the St. Louis basin south of the range. It did not, however, override the portion of the Mesabi Range in this county, but came across the range in Itasca County, and then spread eastward along the south side of the range, in St. Louis County.

The ice from the Patrician district covered the northeastern part of the county as late as the time when the other two ice fields were occupying the southern and western portions, as just described. The morainic system of the Patrician ice sheet, which is correlated with the great morainic system of the Superior lobe, as indicated in the discussion of Lake County, continues into St. Louis County to Vermilion Lake. From that lake northward the Patrician and Keewatin ice fields may have been nearly confluent along a line lying not far from the Vermilion River. Extensive areas of Patrician drift in eastern St. Louis County and along the Mesabi Range are a little older than these great morainic systems, and, as already stated, the Patrician drift of southwestern St. Louis County and neighboring districts was encroached upon by the Superior and Keewatin ice fields and to that extent its drift deposit lies buried beneath their drifts. (See Plate II A and II B.)

The lakes of St. Louis County are estimated to occupy 365 square miles, not including those along the Canadian border. The great majority are less than one square mile in area, but there are a few of considerable size within the limits of this county. The area of Vermilion Lake is about 70 square miles, of Lake Kapetogama fully 30 square miles, of Pelican Lake 20 square miles, and of Trout Lake 11 square miles.

The swamp lands of St. Louis County, as estimated by the State Drainage Engineer in his report for 1906, occupy 1,862 square miles, of which 372 are open swamp with little or no forest growth. Much that is now classed, and which appears in the Land Survey plats as swamp land, will drain naturally when cleared of brush with but little aid by ditching. It is estimated that the rock hills and ranges of St. Louis County embrace an area of nearly 1,700 square miles, or somewhat more than one fourth of the county. The area of dry land with thick drift cover is, however, still larger than the rock areas, being estimated at 2,600 square miles, or about 40 per cent of the county.

The area covered by Lake Duluth in this county is only about 100 square miles, the highest shore line being in places scarcely a mile back from the lake. In the eastern part of the county, however, the distance increases to fully five miles.

The most extensive class of soil in St. Louis County is the stony loam. This is the dominant type in the great morainic system of the Superior lobe which runs southwestward across the southern part of the county, though included among those morainic ridges there are nearly level areas in which a somewhat heavy clay with comparatively few stones occurs. (See Plates XII A, XII B.) The Patrician drift in the eastern part of the county is as a rule exceedingly stony both in the ridges and on the level areas. On the Mesabi Range the drift is in places so thickly set with bowlders as to form a literal pavement. (See Plate XV A). In the district between the Mesabi range and Vermilion Lake there are rough and stony morainic strips (see Plate IX B) between which are nearly plane areas part of which are of sand and gravel and part of stony drift similar to that in the moraines.

In the St. Louis basin, south of the Mesabi Iron Range, there are several classes of soil. A strip several miles wide immediately south of the iron range has a clayey till with relatively few stones imbedded in it, which was deposited by the Keewatin ice sheet. (See Plate II B.) This kind of drift is also present on the south side of St. Louis River in several townships lying east of the Duluth, Winnipeg and Pacific Railroad, and north of White Face River.

Another extensive deposit in the St. Louis basin is a fine sand which borders the river for most of its course from the crossing of the Duluth and Iron Range Railroad down to the crossing of the Coleraine branch of the Duluth, Mesabi and Northern Railroad, and which also spreads westward to within a few miles of the Mesabi range in the drainage basin of Swan River. This sand apparently underlies a considerable part of the muskeg in the western part of St. Louis County.

From the crossing of the Coleraine branch of the Duluth, Mesabi and Northern down the St. Louis and Whiteface valleys there is a deposit composed more of silt than of sand which seems to have been laid down in Lake Upham, the lake which once occupied this area and discharged through the St. Louis River below Floodwood. The same deposit is exposed along the Floodwood River for many miles above its mouth, and is found to underlie the muskeg swamps for some distance north and west of Floodwood. The Meadowlands Experimental Farm in T. 53, R. 19W. lies within the limits of this silt deposit, (see Plates VIII A, VIII B, and VIII C), and a farming district in the vicinity of Floodwood is also developed within it.

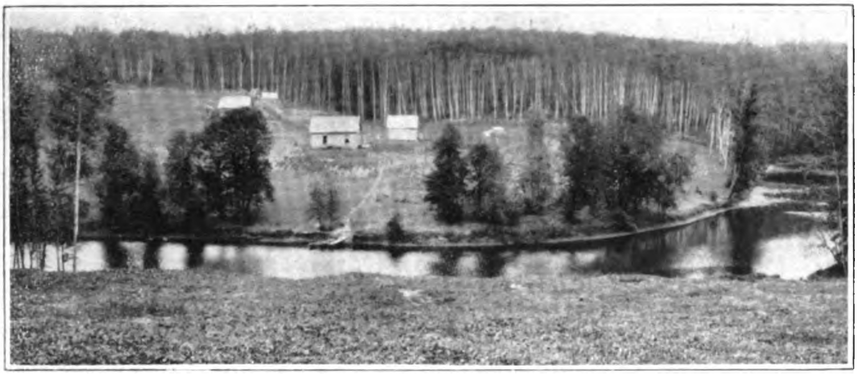
In the area covered by Lake Duluth fully 80 of its 100 square miles have a clayey drift in which stones are relatively scarce compared with their number outside of the lake area. About 10 square miles are embraced in rock ranges in which the drift has been nearly all washed away by lake action. The remaining 10 square miles are occupied by drift of a stony and sandy character. This kind of drift is found chiefly from Duluth southwestward.

In the western part of the county on the borders of Little Fork River (See Plates X A and XI A) and the lower course of Sturgeon River there is an area of over 200 square miles of clayey deposits in which very few stones occur, and which is already being developed extensively, as the soil is productive and easily cultivated. A considerable part of this area as noted above was swept by a forest fire some fifty years ago. Less extensive clayey tracts, occupying perhaps 40 square miles (See Plate IX A), are found along the borders of Vermilion River from T. 65N. to Cr~~ane Lake in T. 67N.,~~ R. 17W. These clayey tracts are in the area once covered by the waters of Lake Agassiz and the material forming the soils may be in part a lake deposit. A large part also of the area covered by Lake Agassiz in northwestern St. Louis County is hilly and many of the hills have little drift coating. There are, however, among the hills, deposits of the calcareous clayey till of the Keewatin ice field, which promise to become productive when cleared and brought under cultivation.

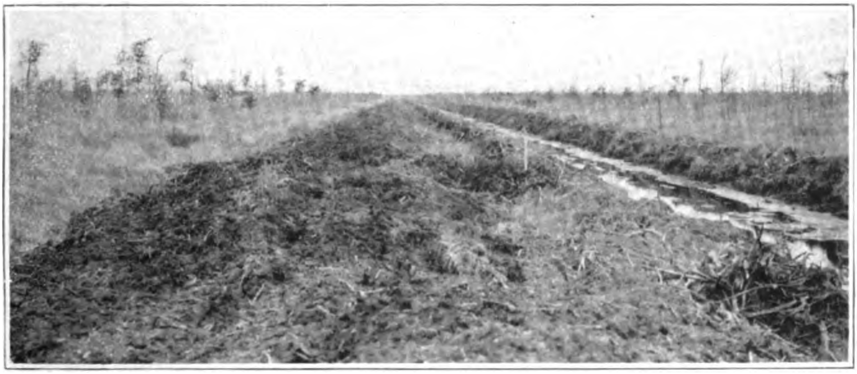
The census of 1910 shows 426½ square miles, or 6.6 per cent of the area of the county, to be in farms, and of these 15 per cent is improved land. The amount of improved land has probably more than doubled in the five years since the census was taken. The crops of 1909 were valued at $919,360. Of this about one third was in hay and forage. The value of the vegetables is placed at $220,556, which is about nine times the value of the cereals of that year ($24,449). The yield of potatoes averages about 150 bushels per acre for the 2,378 acres planted to that crop. Within the past five years many residents of Duluth have invested in small tracts of one to five acres on the hills bordering the city and are developing them rapidly in truck gardens.

KOOCHICHING COUNTY

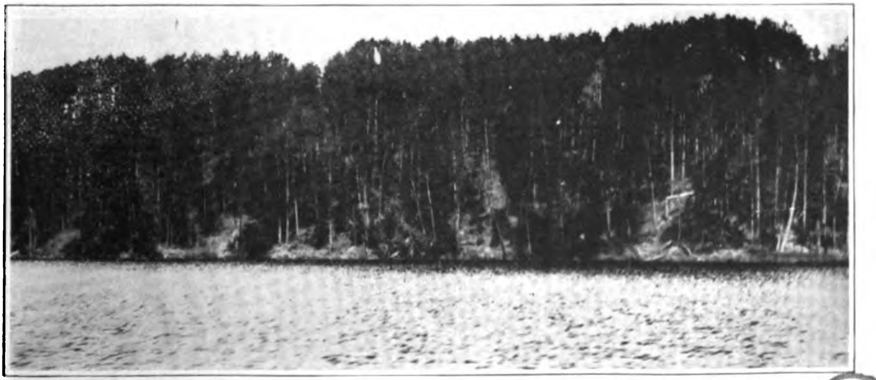
Koochiching County, with International Falls as its county seat, occupies the northwest part of the area under discussion. Rainy Lake and Rainy River form its northern boundary and separate it from Canada. It is traversed from southwest to northeast by the Minneapolis and In-



A. CLEARING IN POPLAR FOREST ON LITTLE FORK RIVER, ST. LOUIS COUNTY



B. DITCHING A MUSKEG IN ST. LOUIS COUNTY



C. JACK PINE OVER 100 FEET HIGH AT STURGEON LAKE, ST. LOUIS COUNTY

UNIV. OF MICH.

ternational Falls Railroad and its northeast corner is crossed by the Duluth, Rainy Lake and Winnipeg Railroad. The Minnesota, Dakota and Western has a passenger line from International Falls to Loman, and a logging road south from Little Fork into Itasca County. The principal inhabitation is along the lines of the railways and along Rainy River. Boat service on Rainy River is maintained from International Falls down to Lake of the Woods throughout the summer season.

The area of the county is 3,141 square miles which was cut off from Itasca County in 1906. Three ranges of townships on its western side, embracing an area of 1,027 square miles, have been described in the report on the northwest quarter of Minnesota, *Bulletin 12,* Minnesota Geological Survey, the 94th meridian being the boundary between the area there described and the portion of the county here discussed.

The greater part of the county falls within the limits of the glacial Lake Agassiz, less than 12 per cent being above the level of the highest shore of that lake. Of the part lying east of the 94th meridian only 170 square miles of the 2,114 are above the level of Lake Agassiz shore lines. The area covered by the lake is nearly half swamp land. The better drained areas are chiefly a calcareous bowlder clay composed of the Keewatin drift. Thin deposits of lake silt have been laid down over the flatter portions. These well-drained areas are largely found on the immediate borders of the streams, although in the eastern part of the county they extend more widely over the interstream areas. In the northeastern part of the county on the borders of Rainy Lake and southward to Lake Kabetogama there are rock hills with very thin deposits of drift on their slopes. South of these rock hills there are ridges of drift which seem to be composed mainly of Patrician drift but which are coated with the calcareous Keewatin drift. They appear, therefore, to be overridden moraines of the former drift. There are other ridges in the vicinity of the Minnesota and International Railroad from Little Fork southwestward for several miles which have a nucleus of Patrician drift and a veneer of Keewatin drift. A few miles farther southwest there is a morainic strip running from northwest to southeast which is crossed by the Big Fork River just below the mouth of Sturgeon River and which runs southeastward on the north side of Big Fork River past Big Falls and thence with slight interruptions to Little Fork River in the east part of T. 65, R. 25W. The same belt reappears between Little Fork and Net Lake rivers and continues southeastward into St. Louis County, passing just south of Net Lake and leading past the south side of Pelican Lake to the west end of Vermilion Lake. This morainic strip seems to have been formed in the main by the Patrician ice field but it carries a somewhat heavy deposit of Keewatin drift. For several miles in the vicinity of Big Falls and in much of its course gravel and sand deposits are abundant, thus distinguishing it from the ridges farther north which are composed chiefly of bowlder clay.

The highest shore of Lake Agassiz is marked generally by a well-defined gravel ridge or beach. Numerous gravelly ridges are also developed at lower levels, some of which appear as narrow strips of dry land traversing the extensive swamps. These have served as lines for highways across the swamps.

Systematic surveys are being made for draining the swamps of this county (see Plate XIV B), under the direction of the County Surveyor, and roads will be constructed along each of the main ditches thus giving openings to the market for areas of farming land which are at present cut off by swamps.

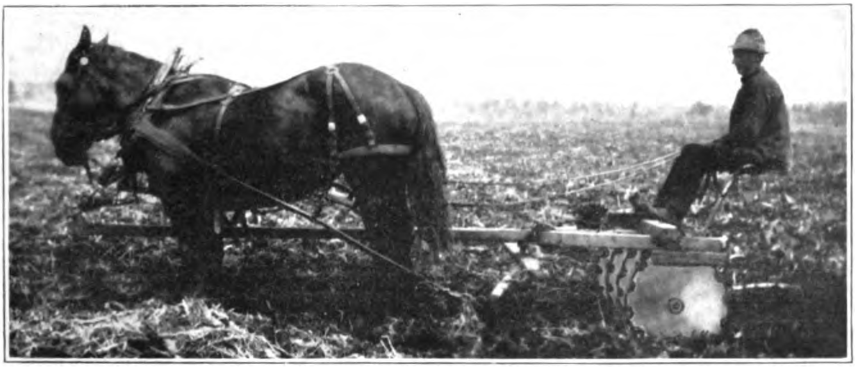
Estimates have been made from field maps of the percentages of each of the several main classes of land in this part of Koochiching County east of the 94th meridian. Similar estimates given in *Bulletin 12*, page 61, show the percentages of the western part of the county.

Percentages of Classes of Land

	Square miles	Per cent of county
Moraine with sandy to gravelly loam soil	87	4.1
Overridden morainic ridges with clay loam soil	19	0.9
Till plain with prevailing clay loam soil	125	5.91
Lake washed drift with clay loam soil	731	34.57
Lake washed drift with sandy loam soil	42	2.00
Sandy and gravelly deposits of old lake shores	54	2.55
Hilly land with rock near surface	55	2.60
Interior lakes	16	0.75
Swamp lands	985	46.62
	2,114	100.00

The census returns for the entire county show that in 1910 only 3.6 per cent of the land area was in farms, and only 7.5 per cent of the farm land was improved. The rapid growth of International Falls has given a good market for farm products in the north end of the county and farms there are being rapidly developed. The clay loam soil, both in the till plains above the level of Lake Agassiz and in the till which has been washed by the lake, may be developed easily into first-class farm land. It has only a moderate number of bowlders and cobblestones except locally where the underlying stony Patrician drift comes to the surface or has been involved with the more clayey Keewatin drift by the readvance of the Keewatin ice over it.

A. FIRST CROP ON LAND STUMPED THE PREVIOUS YEAR AT EXPERIMENT FARM, DULUTH



B. HEAVY STEEL DISK USED IN PREPARING NEW SOIL

C. WINTER VIEW AT DULUTH EXPERIMENT FARM

ITASCA COUNTY

Itasca County, of which Grand Rapids is the county seat, is in the western part of the area herein described~~, and extends also west of the 94th meridian about 20 miles into the area discussed in *Bulletin*~~ *12*. The cutting off of Koochiching County in 1906 has reduced its area to 2,780 square miles. Of this, 470 square miles are west of the 94th meridian.

A line of the Great Northern Railroad crosses the southern end of the county. Other railway lines with termini in the Mesabi Iron Range extend into the southeast part of the county. The Minnesota & Rainy River Railroad has lines running into the northern part of the county which are used chiefly for logging purposes. One of these opens a market for farming districts around the thriving town of Big Fork. The Mississippi River has a low rate of fall and a sluggish current from Grand Rapids to Brainerd, and it is navigated by occasional boats between these cities.

The eastern half of the county is very diversified in topography and in soil. The Mesabi Iron Range runs across the southeast part of the county in a northeast to southwest course and has a moraine or other thick drift covering superposed on it throughout its course in this county. Its highest points in the eastern part of the county rise above the 1,600 foot contour, but the greater part of the range falls between 1,300 and 1,500 feet. There are only a few points at which natural exposures of the rock occur on this range. The large mine pits, however, considerably increase the area of exposure.

There are extensive till plains in the northeast part of the county from the Mesabi range northward. There are also a few rock hills and ridges as indicated on Plate I.

The western half of the county has extensive tracts with level to gently undulating surface, much of which is poorly drained. These areas may be greatly improved by a moderate amount of ditching after the fallen timber and obstructions to drainage are cleared away. The extreme southeast part of the county takes in a few square miles of the great muskeg in the St. Louis River basin. Most of the southern part of the county, however, drains to the Mississippi River below where it crosses the Mesabi Range at Grand Rapids. The northern half of the county is drained to Hudson Bay. A few square miles in the northeast corner lie in the basin that was once covered by the waters of Lake Agassiz.

There are a large number of small lakes among the moraines and in the outwash gravel plains in this county, the combined area of which, as estimated by Mr. George A. Ralph, is 227 square miles. The swamps of the entire county are estimated to occupy 845 square miles, but the area of the swamps can be greatly reduced at moderate expense and changed into fertile till plains. The soil of the till plains is diversified and ranges from fine clayey loam to a loose-textured stony loam. It was found impracticable to map with any accuracy the extent of each kind of soil in these plains. They are accordingly classed in the table below as till with mixed soil, ~~and represented by the letters TM on the map~~.

The moraines are very largely of a loose-textured till with a liberal admixture of bowlders and smaller stones gathered up apparently from the Patrician drift which underlies the Keewatin drift throughout this county. In some cases it is thought that the morainic ridges were formed by the Patrician ice field, for they seem to have but a thin veneer of Keewatin drift. This is especially true of those in the eastern part of the county.

The outwash plains are composed of sandy gravel. They are interrupted more or less by scattered knolls and gently undulating tracts with somewhat gravelly material not easily connected into definite morainic belts.

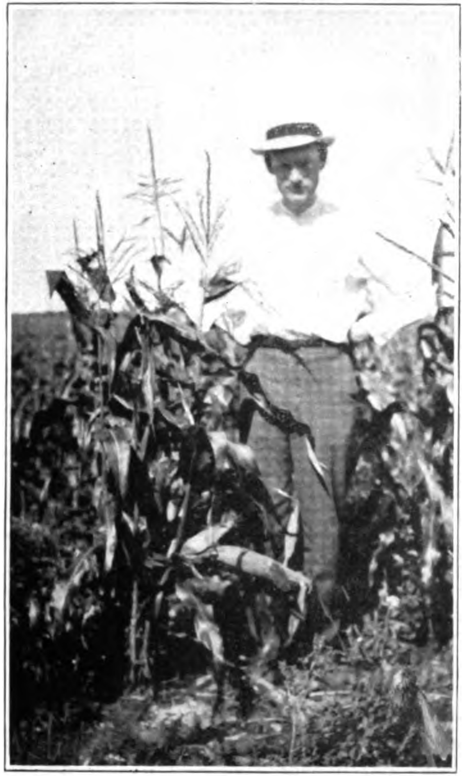
There are numerous places in the northeast part of the county where the relief of ridges is due in part to the altitude of the underlying rock, but there are only a few natural outcrops of rock. The areas in which rock is near the surface are estimated to amount to not more than 25 square miles in the entire county. This includes the places where rock is known to be within a few feet of the surface and the places uncovered by mining, as well as the natural exposures.

The estimates of percentages of different classes of land given in the table below are for the entire county, since only a small part of it was embraced in the estimates given in *Bulletin 12*.

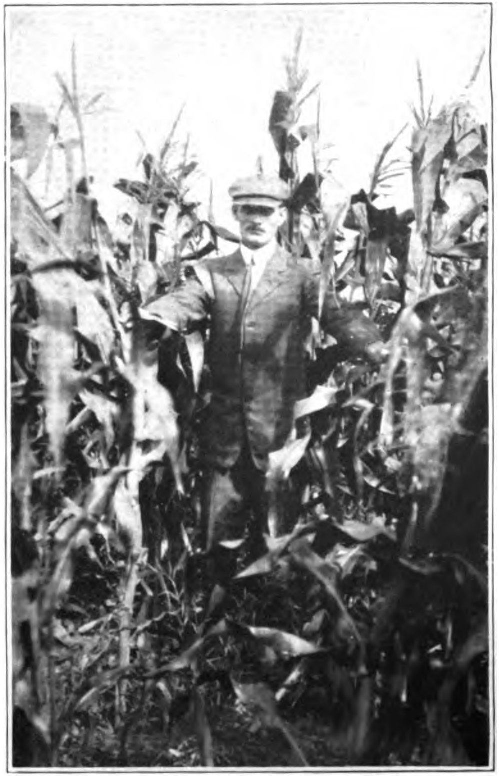
Percentages of Classes of Land

	Square miles	Per cent of county
Moraines chiefly with sandy to stony loam soil	685	24.64
Till plains with variable soil	775	27.88
Gravel plains and other deposits of sandy gravel	225	8.10
Areas with rock near surface	25	.90
Lakes	225	8.08
Swamp lands	845	30.40
	2,780	100.00

The census of 1910 gives 6.2 per cent of the land area of Itasca County in farms, and of this only 12.6 per cent was improved farm land. The farms are developed chiefly along the Mesabi Iron Range in the vicinity of the mining towns. But there are also farming districts south of Grand Rapids, and a few farms are developed along the Great Northern Rail-



A. CORN WITH GOOD SIZED MATURING EAR, AT DULUTH EXPERIMENT FARM



B. CORN SUITABLE FOR ENSILAGE AT DULUTH EXPERIMENT FARM—FIRST CROP

MICH.

way lines in the southeastern part of the county in the vicinity of Swan River, Goodland, Acropolis, and Bengal. As is natural in this region in the vicinity of mining towns, vegetables form the principal crops, and amount to about 30 per cent of the value, while cereals amount to only 4 per cent. Hay and forage in 1909 constituted 24 per cent of the entire crop values.

EASTERN CASS COUNTY

The part of Cass County west of the 94th meridian has been described in *Bulletin 12,* and an area of about 375 square miles east of that meridian remains to be described herein. This is a strip a little more than 10 miles wide and about 36 miles long. It is crossed centrally by the "Soo" Railroad on which is located the thriving village of Remer, the only village in this part of Cass County. The land surface is flat to gently undulating as far south as Remer and much of it is swampy. This part of the county was covered by the Keewatin ice sheet, and its southern limit was about five miles south of Remer at Big Rice Lake. The border of Keewatin drift deposits runs eastward from there to Shovel lake in Aitkin County. Railway cuts between Remer and Shovel Lake expose the Patrician drift beneath the Keewatin and show the more stony character of the former drift. The greater part of the Keewatin drift has a clayey to sandy loam soil with very few bowlders and cobble stones.

From Big Rice Lake southward past Thunder Lake there is a prominent moraine of the Patrician drift which runs eastward, but becomes overridden by the Keewatin drift near Shovel Lake. It contains hills 50 to 100 feet high and is very stony as well as rugged. South of this moraine is a till plain several miles in width with gently undulating surface. This also is very stony but has a soil of sufficient strength to make excellent grazing land. South of this plain is another moraine running from Crooked Lake northeastward into Aitkin County. This also is rugged with sharp knolls and deep basins and its soil is very stony. A few settlers have located on and near it in the vicinity of Mae post office.

NORTHEASTERN CROW WING COUNTY

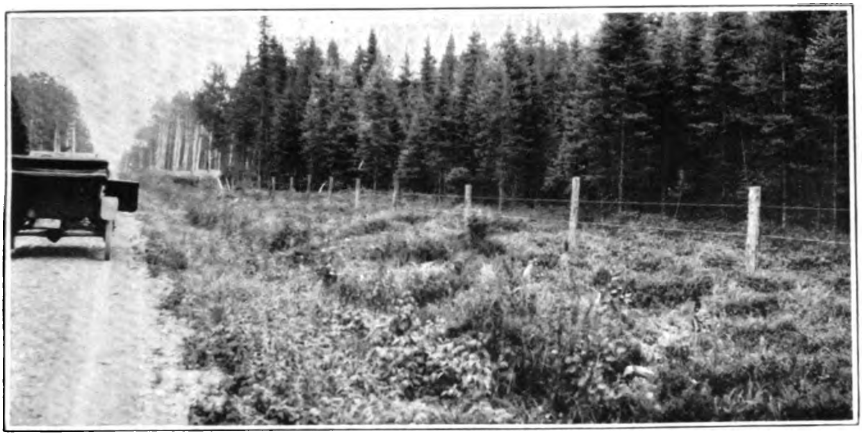
A small area of scarcely 250 square miles in the northeastern part of Crow Wing County lies in this quarter of Minnesota. It is a very diversified area, parts of it being strongly morainic, other parts of it gently undulating, and a strip in the vicinity of the Mississippi River which was covered by Lake Aitkin is very flat. The Keewatin ice extended a small lobe down the Mississippi valley into Crow Wing County as far as Rabbit Lake north of Cuyuna, but not more than 35 square miles of this county are covered by that drift. At its southwest end this area of Keewatin drift encroaches on a prominent moraine of Patrician drift which crosses the Mississippi River west of Rabbit Lake. The part north of the Mississippi has its western border along Little Pine River, there being an extensive gravel plain west of that stream from Emily southward. The moraine becomes diffuse east of Emily but is traceable northeastward into Aitkin County. The part south of the Mississippi sweeps around the west and south sides of Mille Lacs Lake. A till plain with gently undulating surface and only a moderate number of surface bowlders occupies the district northward from Emily to Outing and thence eastward through the northern edge of Crow Wing County into Aitkin County. Parts of this have a rich loose-textured soil. In the morainic areas there are scattered settlers who have selected the land that has relatively few bowlders and easily cultivated soil. The area that was covered by Lake Aitkin lies mainly south of the Mississippi River and usually has a sandy soil except where covered by peat. The subsoil becomes clayey within the depth of a few feet and in places at only a few inches in depth and the land gives good returns under cultivation.

AITKIN COUNTY

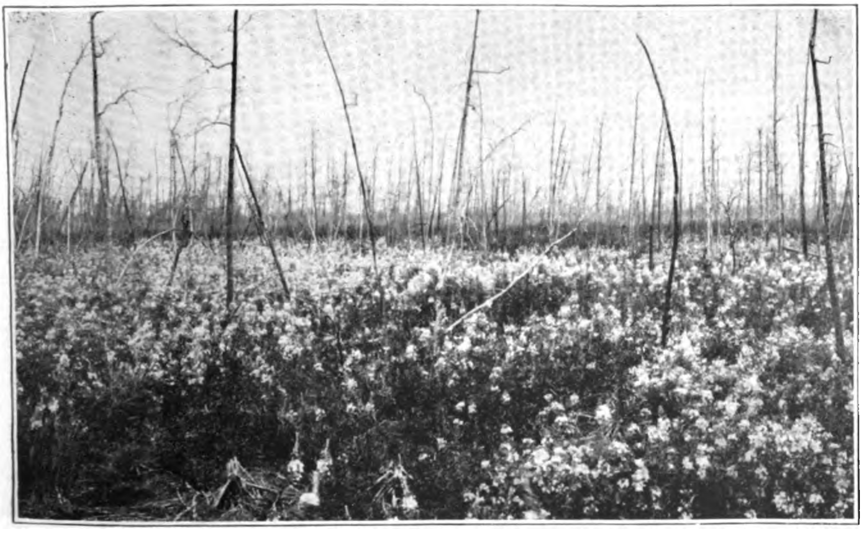
Aitkin County lies mainly in the southwest part of the northeast quarter of Minnesota but extends also a few miles south of the median line of the state and embraces the north half of Mille Lacs Lake, the second largest lake in the state. The entire county is included in the present discussion. Nearly all of it is within the Mississippi River drainage, only a few square miles in the northeast corner being tributary to Lake Superior through St. Louis River. The area of the county is about 1,975 square miles, of which about 200 square miles is occupied by lakes. The area within Mille Lacs Lake is nearly 100 square miles.

A line of the Northern Pacific Railroad running westward from Duluth centrally across the county was for many years the only line of railway in it. But recently three branches of the Soo Line system have been extended across the county, one through the north half, another through the southeast part, and another near the line of the Northern Pacific through the central part. There is also a small railway line running from the Great Northern at Swan River to the thriving town of Hill City in the north part of the county.

Except in the vicinity of Aitkin, the county seat, the entire county is sparsely settled. There is a large amount of swamp land, it being estimated by Ralph that 828 square miles, or about 42 per cent of the county, is too wet for cultivation under present conditions. There are, however, large areas of wet land in the southern half of the county which will need only a slight amount of ditching to get rid of the surplus water after



A. SPRUCE AND POPLAR ON BED OF LAKE AGASSIZ WEST OF COOK



B. MUSKEG IN BED OF LAKE AGASSIZ NEAR BIG FALLS

it has been cleared of brush and timber. The subsoil of these wet tracts is chiefly clay with only a thin cover of peat and muck. The northern part of the county has extensive muskegs with thick deposits of peat, and wire grass marshes with a substratum of sand or silt. The place where these marshes and muskegs are was for some time after the disappearance of the ice occupied by shallow lakes which became drained with the cutting down of the valleys of the Mississippi and St. Louis rivers.

Each of the three drifts, Superior, Patrician, and Keewatin, are present in the county. The Superior drift covers several townships in the southeast part. The Patrician drift is at the surface in the western part of the county and underlies the other drifts in the remainder of the county. The Keewatin drift covers most of the northern half of the county and extends in places a few miles into the southern half. It does not, however, cover the Patrician drift in an area of high land in the northwest part of the county lying south and west of Willow River.

There are several areas of sharply ridged or morainic drift distributed widely over the county and occupying nearly one fourth of its surface. Their distribution may be seen by reference to the general map, Plate I. There are two moraines of the Superior lobe in the eastern part. All the other moraines were formed by the Patrician ice. Those in the northern half were also overridden to some extent by the Keewatin ice. As a result of this overriding the surface has, on the whole, been rendered smoother, but in a few places the later ice movement appears to have shoved up sharp ridges where the surface before had been less sharply ridged.

The sharp knolls and ridges of the moraines are usually composed of gravel and sand and of very stony till. Surface bowlders are also numerous. Such land seems better adapted for grazing than for cultivation, though some good farms have been developed on hills in the southern part of the county.

The level or gently undulating tracts in the midst of the morainic areas, as well as the extensive plains separating the moraines, have usually a productive clay loam soil adapted for agriculture. This is clearly described by Warren Upham who says:

> "The areas of till have everywhere a very productive dark soil, a foot or more in depth, in which the proportion of bowlders and gravel is usually not so great as to hinder plowing. This soil is readily permeable to rains, and in dry seasons gradually yields its moisture to growing crops, so that they are rarely or never harmed by the moderate droughts which occasionally occur in summer. Gentle slopes and good natural drainage generally permit early sowing and planting, and the season of growth between the latest frosts of spring and the first in autumn is usually about four months, permitting a great variety of farm crops to be well matured and ripened. Only small parts of the till areas, consisting of morainic ridges and hills, have too abundant boulders and too steep slopes to be available for

cultivation; and these tracts, when cleared, are suitable for pasturage. Hay is a natural product of the district, for portions of many of the streams are bordered by moist lands from a few rods to a half mile in width, bearing a luxuriant growth of tall meadow grasses, which make one to two tons of hay per acre. Many of the swamps now inclosed by higher ground are capable of drainage by ditches and will then rank as the most valuable farming land."[1]

There is a sandy plain covering from 50 to 60 square miles lying north of Mille Lacs Lake in Tps. 45 and 46 N. and Rs. 25, 26, and 27 W. on which numerous farms have been developed. The water table is very near the surface so that the crops are seldom seriously affected by drought. The soil, however, is much lighter than on neighboring till plains to the east. Another sandy area of a few square miles is found at the extreme end of the Superior lobe in Tp. 45, Rs. 23 and 24W. Aside from this the area occupied by the Superior lobe in Aitkin County is nearly all clayey till; under present conditions much of it is wet and swampy, but may be largely reclaimed by ditching. Along the borders of the Mississippi, from the northern end of the county to where the stream leaves it on the west, farms have been developed. The soil is usually somewhat sandy but is underlain to some extent by a fine lake silt that was deposited in the bed of Lake Aitkin. This soil is, on the whole, as productive as the till areas, and has the advantage of being nearly free from stones. The extensive swamps bordering the Mississippi are rapidly changed into productive farm land when the surplus water has been removed by ditching.

The estimates of percentages of classes of land in the table below are necessarily only rudely approximate in the present sparsely settled condition of the county, and, as noted above, the percentage of swamp land will be very greatly reduced with only a moderate amount of ditching as soon as the land is cleared and the obstructions removed from the natural drainage.

Percentages of Classes of Land

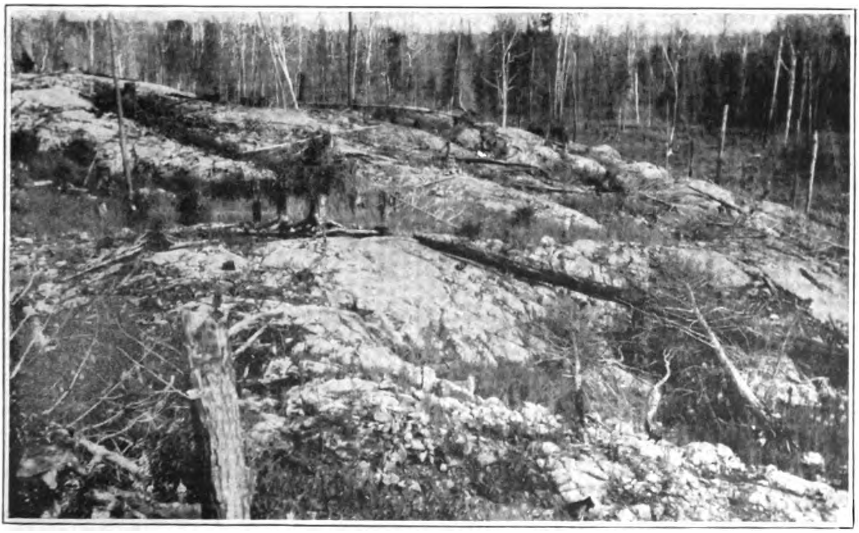
	Square miles	Per cent of county
Moraines chiefly with stony to sandy loam soil	464	23 50
Till plains chiefly with clay loam soil	357	18.00
Sandy plains	121	6.10
Lakes	205	10.40
Swamps and marshes and muskegs	828	42.00
	1,975	100.00

According to the census of 1910 only 15 per cent of Aitkin County was in farms, and only one fifth of this, or 3 per cent of the county, was improved land. Corn and oats are the leading cereals and potatoes the

---

[1] Upham, W. *Aitkin County, Geology of Minnesota* 4:34. 1899.

A. VERY BOWLDERY LAND ON MESABI RANGE NEAR HIBBING. IT ONCE SUPPORTED A GOOD HARDWOOD FOREST



B. ROCKY AREAS IN NORTHEASTERN MINNESOTA. AMONG THE ROCK KNOBS TIMBER THRIVES

UNIV. OF MICH.

leading vegetable. Hay and forage form the principal crop on the farms, and in addition to this there is much wild grass put up as hay. Strawberries and raspberries are important small fruits. Apples and plums are grown successfully as orchard fruits. The prominent hills and ridges in the moraines have a topographic condition favorable for the growth of orchard fruits, since they often escape the frosts that affect the lower lands around them; but as yet very little use has been made of them for orchards.

CARLTON COUNTY

Carlton County is located at the southwest end of the Lake Superior basin, south of the western part of St. Louis County. It has an area of 867 square miles. The eastern portion, comprising less than half of the county, is tributary to Lake Superior, the western part being tributary to the Mississippi, partly through the Kettle River southward into the St. Croix and thence to the Mississippi at Hastings, and partly through Prairie River directly westward into the Mississippi in Aitkin County. Glacial Lake Duluth, which occupied the western portion of the Superior basin, covered fully 150 square miles in the southeast part of the county, chiefly in the basin of the Nemadji River. The St. Louis River enters the area that was covered by Lake Duluth at Carlton and runs near the north edge of that lake area to Lake Superior.

This county was covered by the Superior ice lobe, except a few square miles in the northwest corner in which both the Patrician and Keewatin drifts are exposed. The moraines of the Superior lobe run from northeast to southwest across the portion of the county lying north of the axis of the Superior lobe and the bed of Lake Duluth. The moraines south of the basin and bed of Lake Duluth have a nearly east to west trend in southern Carlton and northern Pine counties. The morainic areas occupy about one third of the surface of the county, not including extensive areas of outwash associated with them, which, together with the lines of glacial drainage embrace nearly one eighth of the county. It is thought that some of the more prominent moraines along the north side of the Lake Duluth area have a nucleus of Patrician drift of morainic character. The trend of the moraines of the Patrician ice sheet here is very similar to that of the moraines of the Superior lobe, but the ice laid on the northwest side of the Patrician moraines, or directly opposite the position which the Superior lobe presented to its moraines in this particular district. The Patrician ice, however, had melted away from its moraines before the Superior ice advanced over them.

There are extensive till plains in the western half of the county covering over 200 square miles. There are also extensive swamps in that portion, chiefly among the morainic areas, but also to some extent among the till plains. Rock ledges are exposed chiefly along the valley of St. Louis River, and along Moose River below Barnum, there being only occasional outcrops of a few acres in a place elsewhere. There are relatively few lakes and their combined area is estimated to be but 9½ square miles.

The greater part of this county has a rich soil of clay loam and sandy loam, and bowlders are seldom so numerous as to greatly interfere with the cultivation of the land. A compact clay occupies much of the bed of Lake Duluth.

The United States Bureau of Soils has prepared a map and description of several townships in the northeast part of the county and of the neighboring part of St. Louis County, Minnesota, and Douglas County, Wisconsin. In this the area covered by Lake Duluth is largely classed as Superior clay. The sandier portions on the northwest border of the lake are classed in part as Superior silt loam, in part as Miami sandy loam, and in part as Miami fine sand. The morainic areas are classed chiefly as Miami stony loam, though areas in the vicinity of Barnum are designated as Barnum stony loam, and Barnum loam, and those near Sawyer as Miami sandy loam. The areas of outwash are largely classed as Miami sand, but they also embrace parts of the Miami sandy loam. They include also the Miami gravelly sandy loam found extensively from Cloquet southward to Otter Creek, and part of the Barnum stony loam from Atkinson to Mahtowa. The area mapped as Miami gravelly sandy loam north of Cloquet is very different from that south. It is a morainic area while that south of Cloquet is outwash. Reference may be made to the report on this area published as a part of the *Annual Report of the Bureau of Soils* for 1905 for descriptions of the soils and their agricultural possibilities.

The following table presents the percentages of classes of land as determined on the geologic basis. Owing to the lack of roads in certain parts of the county where settlements have not yet reached the estimates are necessarily only rudely approximate.

Percentages of Classes of Land in Carlton County

	Square miles	**Per cent of county**
Morainic areas outside Lake Duluth chiefly sandy and stony loam	273	31.50
Waterlaid moraines in Lake Duluth	26	3.00
Till plains, clay loam to sandy loam	212	24.40
Gravelly and sandy outwash and glacial drainage	102	11.80
Sandy plains in Lake Duluth	20	2.30
Clayey plains in Lake Duluth	111	12.80

Rock ledges	3½	0.40
Lake areas	9½	1.10
Swamp lands	110	12.70
	867	100.00

The waterlaid moraines in the bed of Lake Duluth have considerable expression for a few miles west from Barker, the topography being nearly as sharp as that of landlaid moraines. In the remainder of the lake area, however, waterlaid moraines are very inconspicuous. They determine to some extent the course of streams tributary to the Nemadji River even where lacking in surface expression.

The census of 1910 reports 21.7 per cent of Carlton County to be in farms, of which 22.8 per cent is improved land. Oats, wheat, and barley are the main cereal crops, rye and corn being grown in less amount. Potatoes are the main vegetable crop. Apples and plums are successful orchard fruits, and berries of all kinds are found very productive. In this county, as well as in other parts of northeastern Minnesota, wild raspberries are very abundant and large numbers of the residents resort to the unappropriated lands for them in the berrying season.

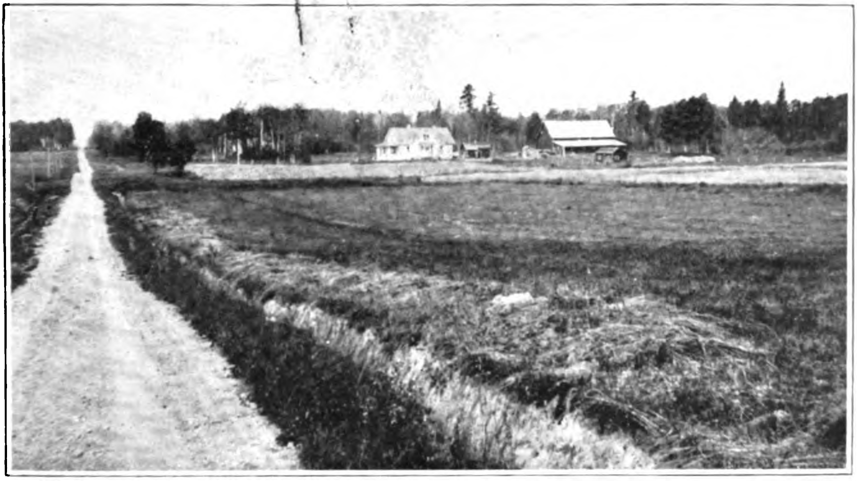
INDEX

Page
Acknowledgements 5
Agassiz Lake.........6, 15, 17, 20, 47, 49, 59
Agricultural conditions.................45-69
Agriculture, relation to geology......... 1
Aitkin County 64
Altitude 7, 8
Annual Report of the Bureau of Soils.... 68
Atkinson 68
Baptism River 53
Barker 69
Barnum loam 68
Barnum stony loam.................... 68
Beaver Bay 53
Big Falls 59
Big Fork 61
Big Fork River........................ 59
Big Rice Lake........................ 63
Brainerd 61
Brule Lake............................ 51
Carlton County........................ 67
Cascade River 51
Cass County, eastern part of........... 63
Climatic conditions of Minnesota.......24-44
Cloquet 68
Cloquet River......................... 53
Birch Lake 55
Cook County........................... 49
Coteau des Prairies.................... 7
County reports 49-69
Crooked Lake.......................... 63
Crop-growing season 35
Crow Wing County, northeastern part of.. 63
Drainage 10
Drainage Engineer, State...........5, 56, 61
Driftless area......................... 19
Duluth, Lake..16, 17, 47, 49, 50, 58, 67, 68, 69
Earthy mantle 12
Elfman, A. H., work of..............3, 5, 51
Emmons, W. H., introduction by........ 1
Eskers 53
Field work............................ 5
Fires, effect of.......................22-23
Floodwood 57
Forest, National..................2, 46, 51
Forests 21
Frosts 32
Geological and Natural History Survey of
Minnesota 5
Glacial deposits....................13-15, 46
Glacial features 16-17
Glacial lake features..................17-19
Gravel ridges......................... 60
Hastings 67
Hinckley fire......................... 23
Hudson Bay drainage system............ 10
Humidity 40, 43

Page
International Falls.................... 60
Introduction 1-4
Isabella River 52
Kapetogama, Lake 56
Keewatin drift................47, 48, 59, 62
Keewatin Ice Sheet.................17, 56, 65
Kettle River.......................... 67
Killing frosts, dates of...............33, 34
Knife River 53
Koochiching County 58
Labrador Ice Sheet.................... 16
Lake Agassiz..........6, 15, 17, 20, 47, 49, 59
Lake Aitkin....................18, 47, 66
Lake County.......................... 51
Lake deposits 15
Lake Duluth..16, 17, 47, 49, 50, 58, 67, 68, 69
Lake Kapetogama 56
Lake of the Woods.................... 59
Lake Traverse 17
Lake Superior, drainage to............. 10
Lake Superior, level of................ 7
Lake Upham.....................18, 47, 57
Lake Vermilion 55, 56
Lakes 11, 56
Lakes, area.........................50, 56
Land classification 45-69
Leaf Hills 7
Leech Lake........................... 11
Length of Minnesota.................. 6
Lime 22
Limestone 22
Little Fork 59
Little Fork River...............18, 58, 59
Loess 12-13
Mahlowa 68
Manitou River 53
Maps, use of.......................... 4
Marl 22
Meadowlands Experiment Farm.......... 57
Mean annual temperature............... 26
Mesabi Iron Range..............55, 57, 61
Miami fine sand....................... 68
Miami sandy loam..................... 68
Mille Lacs.................11, 16, 64, 66
Minnetonka 11
Mississippi River, rate of fall.......... 61
Mississippi River drainage system........ 10
National Forest....................2, 46, 51
Nemadji River 67, 69
Net Lake 59
Northwest Angle 6
Otter Creek 68
Patrician drift..48-49, 52, 56, 57, 59, 62, 65, 67
Patrician Ice Sheet.................... 16
Pelican Lake 55
Pigeon River 51

Page
Posey, C. J., work of ... 4
Precipitation ... 36-40, 43, 44
Purssell, U. G., acknowledgements to ... 4
  chapter on Climate by ... 24-44
Railway facilities ... 45, 55, 59, 61, 63, 64
Rainy days, number of ... 41
Rainy Lake ... 58
Rainy River ... 58
Ralph, George A., estimates by ... 5, 56, 61, 64
Red Lake ... 11
Red River ... 2
Relief ... 8
Residuary material ... 12
Rock areas ... 11
St. Croix River ... 67
St. Louis County ... 55
St. Louis River ... 53
"Sawtooth Range" ... 7, 50
Shovel Lake ... 63
Snowfall ... 40, 41
Soil, general conditions ... 19-20
Soils, report of Bureau ... 68
Soils, United States Bureau of ... 68
Stony River ... 52
Stream deposits ... 15
Sunshine, amount of ... 41
Superior clay ... 68
Superior ice lobe ... 49, 65, 66
Superior National Forest ... 2
Superior silt loam ... 68
Surface geology ... 11-19
Swamps ... 2, 46, 59, 60, 61, 67

Page
Temperance River ... 51
Temperatures ... 25, 32, 38, 39
  highest ... 30
  in January ... 28
  in July ... 29
  lowest ... 31
  mean annual ... 26, 27
  monthly ... 27
  seasonal ... 32
Till plains ... 6, 61, 62, 67
Topographical and Drainage Survey of Minnesota for 1906 ... 5
Topography of Minnesota ... 6-7
Trout Lake ... 56
United States Bureau of Soils ... 68
United States Geological Survey, co-operation with ... 3
Upham, Lake ... 18, 47, 57
Upham, Warren, acknowledgements to ... 5
Upham, Warren, quotation from ... 65
Vegetation ... 20
Vermilion, Lake ... 55, 56
Weather Bureau, acknowledgements to ... 2
  work of ... 25
Weathering ... 20, 22
Wind-blown sand ... 13
Width of Minnesota ... 6
Winchell, N. H., acknowledgements to ... 5
Wind deposits ... 12
Winds ... 40, 42
Winnebigoshish, Lake ... 11



A. FARM ON CLAYEY KEEWATIN DRIFT EAST OF COOK

B. PIONEER MARKETING AT COOK

UNIV. OF MICH.

The University of Minnesota

MINNESOTA GEOLOGICAL SURVEY
William H. Emmons, Director

IN COÖPERATION WITH THE UNITED STATES GEOLOGICAL SURVEY

BULLETIN NO. 14

SURFACE FORMATIONS AND AGRICULTURAL CONDITIONS OF THE SOUTH HALF OF MINNESOTA

BY
FRANK LEVERETT
AND
FREDERICK W. SARDESON

WITH A CHAPTER ON

CLIMATIC CONDITIONS IN MINNESOTA

BY
U. G. PURSSELL

MINNEAPOLIS
The University of Minnesota
1919

CONTENTS

- Introduction 1-4
- Chapter I. Physical features of Minnesota 5-22
  - Topography of Minnesota 5-9
    - General statement 5
    - Altitude 6
    - Relief 6
    - Drainage 6
    - Lakes 7
  - Surface geology 10-18
    - Rock areas 10
    - The earthy mantle 10
      - General statement 10
      - Residuary material 11
      - Wind deposits 11
      - Glacial deposits 11
      - Stream deposits 14
      - Lake deposits 14
    - The glacial features and their history 14
    - Glacial lake features 16
  - General soil conditions 18-22
    - Vegetation 19
    - Weathering 19
    - Lime 21
    - Effect of fires 21
- Chapter II. Climatic conditions 23-44
  - Introduction 23-24
  - General climatic conditions 24-44
    - Temperature 24
    - Frosts 31
    - Precipitation 36
    - Snowfall 40
    - Winds 40
    - Relative humidity 41
    - Number of rainy days 41
    - Sunshine 41
- Chapter III. Agricultural conditions and land classification in the south half of Minnesota 45-62
  - General statement 45
  - Driftless area 45-46
  - Loess-covered pre-Wisconsin drift 46-47

Minnesota University Library 4-20-21

Old gray drift (Kansan) with little or no loess cover........ 47
Iowan drift over Kansan drift.......................... 47-48
Old red drift (Illinoian) over old gray drift (Kansan)..... 48-49
Young or Wisconsin red drift (Patrician ice sheet)........ 49-50
Young or Wisconsin red drift (Labradorian ice sheet)...... 50
Border of young gray drift (Keewatin ice sheet) in central Minnesota 50-51
Border of young gray drift in southwestern Minnesota...... 51-52
Moraines of southwestern Minnesota..................... 52-53
Moraines of southeastern Minnesota..................... 53
Overlap of red drift by gray drift in Grantsburg lobe........ 53-54
Gray drift moraines of central Minnesota................. 54-55
The great plain of the Minnesota lobe..................... 55-56
The great Red River plain............................... 56-57
The Lake Agassiz area.................................. 57
Outwash sand and gravel plains.......................... 57-58
Alluvial bottoms 58
Farming development in Minnesota....................... 58-60
Rank of different crops in Minnesota..................... 60-62
Relation of crop values to farm investments in southern Minnesota 62

Chapter IV. Descriptions of counties........................ 63-142
Pine County 63-64
Southern Aitkin County............................. 64-65
Kanabec County 65-66
Mille Lacs County.................................. 66-67
Southern Crow Wing County......................... 67-68
Southern Cass County............................... 68
Morrison County 68-70
Todd County 70-71
Southern Otter Tail County.......................... 71-72
Douglas County 72-73
Grant County 73-74
Wilkin County 74-75
Traverse County 75-77
Big Stone County 77-78
Stevens County 78-79
Pope County 79-81
Stearns County 81-82
Benton County 82-83
Sherburne County 84-85
Isanti County 85-86

Anoka County 86-87
Chisago County 87-88
Washington County 88-89
Ramsey County 89-90
Hennepin County 91-92
Wright County 92-93
Meeker County 93-94
Kandiyohi County 95-96
Swift County 96-97
Chippewa County 97
Lac qui Parle County 98
Yellow Medicine County 99
Renville County 100
McLeod County 101
Sibley County 101-2
Carver County 102-3
Scott County 103-4
Dakota County 104-6
Goodhue County 106-9
Rice County 109-11
Le Sueur County 111-12
Nicollet County 112-13
Brown County 113-14
Redwood County 114-15
Lyon County 115-16
Lincoln County 116-17
Pipestone County 117-19
Murray County 119-20
Cottonwood County 120-21
Watonwan County 121-22
Blue Earth County 122-24
Waseca County 124-25
Steele County 125-26
Dodge County 126-27
Olmsted County 127-28
Wabasha County 128-29
Winona County 129-31
Houston County 131-32
Fillmore County 132-33
Mower County 133-35
Freeborn County 135-36
Faribault County 136-37

Martin County 137-38
Jackson County 138-39
Nobles County 139-41
Rock County 141-42

LIST OF ILLUSTRATIONS

Plate I. Map of the surface formations of Minnesota.....in pocket

II. A. Bed of Lake Agassiz near Wheaton

B. Grain field in bed of Lake Agassiz near Wheaton

C. Gray drift till plain in Chisago County........ 58

III. A. Cultivated red drift till plain near Foley

B. Red drift till plain with forest near Foley

C. Boulders on red drift till plain near Foley..... 62

IV. A. Gray drift moraine north of St. Paul

B. Red drift moraine with coating of gray drift north of St. Paul........................ 90

V. A. Wisconsin, or young red drift, moraine near Stillwater

B. Old red drift moraine near Hampton......... 92

VI. A. Outwash plain east of Anoka

B. Outwash plain of gray drift west of White Bear

C. Outwash plain with thick clayey covering north of St. Paul.............................. 94

VII. A. Slope of the Coteau des Prairies near Canby. Gray drift moraine

B. Eroded upland in old gray (Kansan) drift northeast of Zumbrota

C. Broad valley cut in old gray (Kansan) drift west of Kenyon.......................... 108

VIII. A. Loess-covered driftless area near Caledonia

B. Valleys bordered by limestone tablelands near Hampton 132

IX. A. Zumbro valley near Rochester

B. Valley of Rollingstone River near Minnesota City

C. Mississippi valley at Minnesota City.......... 140

TEXT FIGURES

Fig. 1. Altitude map of Minnesota 8
2. Map of glacial drifts, loess, and glacial lakes 13
3. Map showing distribution of forest and prairie 20
4. Map showing mean annual temperatures 25
5. Map showing mean temperatures for January 27
6. Map showing mean temperatures for July 28
7. Map showing highest known temperatures 29
8. Map showing lowest known temperatures 30
9. Map showing average date of last killing frost in spring .. 32
10. Map showing average date of first killing frost in autumn 33
11. Map showing number of days of the average crop-growing season 34
12. Map showing the average annual precipitation 35
13. Diagram showing comparative monthly precipitation 37
14. Diagram showing mean monthly rainfall and mean monthly temperatures at several stations 38
15. Diagram showing rainfall and temperatures at St. Paul from 1837-1913 39

SURFACE FORMATIONS AND AGRICULTURAL CONDITIONS OF THE SOUTH HALF OF MINNESOTA

BY FRANK LEVERETT AND FREDERICK W. SARDESON

INTRODUCTION

BY W. H. EMMONS

Soil is the loose unconsolidated material which nearly everywhere covers the surface of the earth and in which plant life may be maintained. It is made up of finely divided rock in which decaying vegetable matter and animal matter are mingled. A soil is generally in a state of change. It is being washed little by little to the creeks and rivers which carry it to the sea, where it often forms delta deposits; if no new soil formed, hard rock would finally be exposed instead of the loose plant-producing soil. But rocks at and near the surface are continually changing and new soil is being formed from the underlying rock or from loose clayey or gravelly material that may constitute the subsoil, or from bowldery material that at many places in Minnesota lies between the hard rock and the soil.

Water and air attack rock matter and break it down. Heat and cold, freezing and thawing, shatter the rocks and give plants an opportunity to send roots into the cracks that are formed, and these, prying the rocks apart, reduce them to particles of still smaller size. Even the hard solid rocks are ultimately broken down; a building of good solid stone may crumble in a few hundred years, especially in a moist climate.

Some of the rocky matter is dissolved by the water and carried to the sea in solution. It is such dissolved material that makes water "hard" and that gathers in the bottom of a vessel when water is boiled. But not all of the soluble substances are dissolved and carried away; some remain in the soil, and the character of the soil depends largely upon these. Some soils are acid because they have not enough lime. Some are deficient in potash or phosphates, which are necessary if soil is to produce certain crops satisfactorily.

Because it forms the soil, the composition of the underlying material is of great importance. In Minnesota most of the soil is the weathered portion of glacial drift or of lake beds and other features connected with the deposition of the drift. Long ago nearly all of what is now the state of Minnesota was covered over with a great ice sheet hundreds of feet thick that slowly moved down from the Canadian highland carrying with it rocky material which it had gathered in the north. When the ice melted it left large quantities of rock and soil that had mingled with the ice, and this material is the loose drift that lies between the hard rock and the surface. At many places where it is not yet disintegrated it appears as large numbers of bowlders mixed with clay. Although the ice sheet moved very slowly, perhaps not more than a few rods a year or even less, it was active for a long period and locally it scoured the country clean of soil and loose material which, on melting, it piled up somewhere else.

This statement of the origin of the loose material or drift is not speculation, but is substantiated by the most convincing facts. The deposits and all of the features of the country formerly covered with ice are like those that may now be observed in Greenland or Antarctica, where the slowly moving ice fields or glaciers still cover bodies of land of continental proportions. Glacial bowlders, bowlder clay, scratches on the rocks, morainal hills and kettles, all ordered with respect to definite features of the former ice sheet, may be seen at thousands of places in Minnesota.

The ice sheet covered the entire state of Minnesota except the southeastern corner, embracing Houston County and the eastern part of Winona County. This territory is in the driftless area. The higher country within the driftless area is covered with a residuary clay formed during the long period when the rock was undergoing decay. Above this there is generally a covering of wind-blown silt-loam, or loess, which increases the productivity of the soil.

The advance of the ice toward the south was not a single isolated invasion. There were warm periods during the glacial epoch when the ice melted much faster than it advanced, and when the edge of the ice retreated far to the north. Probably the entire ice cap was melted several times during the long period of the ice invasions.

During the intervals when the country was free from ice, rock decay or weathering went on much as at present. Later the succeeding ice sheets covered the larger portions of these weathered surfaces, within the glaciated region. The later ice sheets, however, did not cover exactly the same areas that were covered by preceding ones. In places the deposits left by older ice sheets project beyond the edges of the deposits left by later ones. One may distinguish between them by the difference in the amounts of their decay and in some cases by differences in their material and in the character of the topography of their surfaces. Where deposits of one sheet are covered by those of a later one, the older drift sheet may be revealed where streams cut through the later one or where excavations penetrate it. At some places an ancient soil formed by rock decay and carrying the remains of ancient vegetation marks the contact between the older and the younger drift. The boundaries of the drifts of various ages and the character of the soils formed by them are discussed on pages that follow.

Swamps are very numerous in Minnesota. They are portions of the old lake beds and other poorly drained areas and are of little value for agriculture until drained. Since the ice melted a growth of vegetation has been established on them and great thicknesses of partially decayed vegetation have accumulated in them. This forms the peat which is found in so many of the swamps. Some of it is very thick and will doubtless become a valuable asset in the future when other fuels shall have become more costly.

The great productivity of Minnesota soils is due, not only to their recent origin by reason of which nearly all of them still contain the soluble mineral foods for plants, but also to a favorable climate. The low temperatures which frequently prevail during certain periods in winter make for healthful conditions for animal life and they also benefit plant life. The rainfall, though not excessively great, is sufficient and, since most of it occurs during the growing period, drouths are rare and crop failures almost unknown except in the more sandy soils, which are, however, adapted to quick-growing crops like potatoes. As shown herein, the length of the crop-growing season, that is, the time between late spring frosts and early autumn frosts, is between 100 and 170 days for all except the extreme northeast corner of the state. The long days, high proportion of sunshine, and the moderate humidity are all favorable to plant growth.

This bulletin treats the soils of only the south half of Minnesota. The field embraced includes the part of the state south from the median line, which is near latitude 46° 25′.

Following the plan in *Bulletin No. 12,* on Northwestern Minnesota, a brief general description of the surface features and deposits of the entire state is given, and the climate of the entire state also is discussed. It will be followed by a report on the entire state, the field work for which already has been completed. The work has been done in accordance with the agreement for coöperation between the United States Geological Survey and the Minnesota Geological Survey, entered into, March, 1912. By this agreement the services of Mr. Frank Leverett were secured for surveying the surface formations and soils. Mr. Leverett has been engaged since 1886, or thirty-two years, in studying the surface geology of the Great Lakes region and because of his large experience in the greater area he was particularly well prepared to undertake the studies in Minnesota. He has spent, moreover, considerable time in the state studying its physiography in connection with the preparation of a monograph for the United States Geological Survey. Since the reorganization of the State Survey, the salary of Mr. Leverett has been met by the United States Geological Survey, while the greater part of his expenses have been paid by the State Survey: The State Survey has provided also for this work the services and expenses of Professor F. W. Sardeson, who has assisted in this work for five seasons. We wish to acknowledge the generous assistance of the Division of Soils of the Department of Agriculture of the University of Minnesota and of the United States Bureau of Soils. The valuable contributions to the knowledge of the surface formations of Minnesota by the Minnesota Geological and Natural History Survey, under the direction of Professor N. H. Winchell, particularly those of Mr. Warren Upham of that survey, have aided greatly in the preparation of this report. The section on climatic conditions in Minnesota has been generously contributed without any cost to the Survey by Mr. U. G. Purssell, Director of the Minnesota Section of the United States Weather Bureau. In the preparation of the maps and other data showing dates of killing frosts, lengths of growing season, rainfall, etc., Professor C. J. Posey has rendered efficient service.

The cost of preparation of this report has been met by the Minnesota Geological Survey and the United States Geological Survey. This bulletin is printed by the Minnesota Geological Survey. Arrangements have been made so that land and colonization companies can secure these reports at actual cost of printing, and it is expected that this arrangement will secure a wide distribution. The maps are not intended to be used as a basis for the purchase of land; they do not give an accurate description of each forty-acre tract or each section, but they show the general classification of the land, its climate, and its surroundings.

CHAPTER I

PHYSICAL FEATURES OF MINNESOTA

TOPOGRAPHY OF MINNESOTA

GENERAL STATEMENT

The position of Minnesota is near the center of the North American Continent, and the state embraces an area of 84,682 square miles, of which about 93 per cent is land and 7 per cent water. Its extreme length is nearly 400 miles, from latitude 43° 30′, at the Iowa line, to a point about 23 miles north of the 49th parallel, in the projection known as the Northwest Angle, northwest of Lake of the Woods. The greatest width is 367 miles, but the average width is only about 225 miles, or but little more than half of the length.

Minnesota presents more variety in surface features than most of the north central states, yet a great part of its surface is level or only gently undulating. The flattest portion falls largely in the northwest quarter, and was once the bed of the glacial Lake Agassiz, a lake held in on the north, in central Canada, by the great ice sheet. The roughest portion is in the northeastern quarter. This part is composed largely of volcanic formations and iron-bearing rocks which, though glaciated, were not everywhere buried beneath the glacial deposits. In the southeastern part of the state deep erosion valleys along the Mississippi and its tributaries present bold rock bluffs 300 to 600 feet high. The interior and southern parts of the state have features due almost entirely to the work of the great ice sheets, which at successive times, and from different directions, overspread Minnesota. The glacial deposits comprise an intricate system of moraines with undulating to hilly surface, associated with which are level outwash plains of sand and gravel, and gently undulating intermorainic till plains. The moraines were formed along the border of the ice at definite lines where the edge of the ice held its position for a relatively long time. They consist of sharp knolls and inclosed basins and also of more or less parallel ridges which, however, interlock in places. These moraines are distributed in rudely concentric systems which mark successive positions of the border of each ice sheet as it was melting off from this region. The outwash plains lie on the outer border of the moraines, where sandy gravel was spread out by dirt-laden waters escaping from the ice. The till plains lie along the inner or iceward border of the moraines and represent areas over which the ice border melted back somewhat rapidly, forming relatively few knolls and ridges.

ALTITUDE

The altitude of Minnesota ranges from 602 feet, the level of Lake Superior, up to 2,230 feet, on high rock hills in the northeast part of the state, in western Cook County. The small map, Figure 1, shows that a large part of the state falls between 1,000 and 1,500 feet. The average altitude of the state is not far from 1,200 feet. The portions above 1,500 feet lie chiefly in two areas, one at the northeast and one at the southwest corner of the state, though there is a good sized area around the sources of the Mississippi River in the western part, and several smaller areas in that vicinity; one of these in the southern part of Otter Tail County is known as the Leaf Hills. The altitude of the elevated area in the southwestern part falls short a little of reaching 2,000 feet, but that in the northeastern part includes several small areas, chiefly in Cook County, that rise above 2,000 feet. The portions below 1,000 feet fall in two areas widely separated except for a connecting line along the Minnesota valley, one being on the western edge of the state and the other on the eastern. There is also a narrow strip bordering Lake Superior.

RELIEF

The most conspicuous relief is found in the "Sawtooth Range" and other prominent ridges that closely border Lake Superior and which rise abruptly from 500 to 900 feet above the lake. The rock ranges lying back from the shore, though more elevated than those fronting on the lake, seldom rise more than from 200 to 300 feet above the swamps and lakes among them. In fact several of the lakes of Cook County are above 1,900 feet or within 300 feet of the level of the highest points in the state. The most prominent part of the Mesabi Iron Range in St. Louis County rises from 400 to 450 feet above bordering plains. The Coteau des Prairies rises about 700 feet above the plain northeast of its border, but in Minnesota the rise is usually spread over a space of from 12 to 15 miles or more in width, so that the elevation can scarcely be appreciated by one crossing over it. There is a rather rapid rise of from 300 to 500 feet to the sharp range of hills in Otter Tail and Becker counties from the Red River valley. This rise is of especial interest since it seems to have some influence on the rainfall, the precipitation being greater in these hills where air currents are forced upward and cooled than in the bordering lower lands to the north, west, and south.

DRAINAGE

The drainage of Minnesota is widely divergent, part of it leading to the Gulf of Mexico, part to the Gulf of St. Lawrence, and part to Hudson Bay. The Gulf of Mexico receives about 57 per cent, the St. Lawrence less than 9 per cent, and Hudson Bay fully 34 per cent of the drainage. There was a time, however, after the glacial ice had melted from Minnesota but was still occupying the northeast part of the Superior basin and neighboring parts of Ontario and Manitoba, when all the drainage was southward to the Gulf of Mexico. The western Superior basin then overflowed into the St. Croix River, while the Red River drainage basin, largely covered by Lake Agassiz, drained southward through lakes Traverse and Big Stone into the Minnesota valley.

The drainage to the south, or Gulf of Mexico, has generally a gentle descent, and waterfalls are rather rare, though the Mississippi has notable falls at Minneapolis and there are one or more falls or rapids on several of the tributaries. The drainage to Lake Superior is generally rapid and nearly every stream has several cascades. There is, however, a wide area of the upper St. Louis basin in which that stream and its tributaries have relatively gentle descent for many miles. The Hudson Bay drainage has a few rapids and waterfalls in the headwater part of Rainy River and its tributaries, but Red River and its main Minnesota affluent, Red Lake River, have no falls since no outcrops of solid rock occur along them. There is, however, very rapid descent for a few miles along Red Lake River and its tributary Clearwater River in Red Lake County. Red River is subject to great freshets because its lower course often remains frozen after the southern or headwater part has broken up. Thus ice jams are formed which divert the waters from the channel over the bordering plain.

The streams of these several drainage systems are interwoven in part of the area, there being no prominent dividing ridges to separate them. In some cases a swamp may be drained either to Hudson Bay or to the Gulf of Mexico, while other swamps may be drained either to the Mississippi or to Lake Superior.

LAKES

Throughout much of Minnesota, except the northwest, southwest, and southeast corners, small lakes are a common feature. They usually occupy basins among the moraine ridges and knolls and on the outwash plains, but occur to some extent also on the till plains and among rock knobs. The combined area of the lakes within the state is estimated to be about 5,650 square miles, or nearly 7 per cent of the entire area. The largest lake is Red Lake, a very shallow body of water with an area of 440 square miles. Other large lakes are Mille Lacs, also very shallow, Leech, Winnibigoshish, and Minnetonka. Minnetonka and the southern part of Leech Lake extend into a network of deep depressions among morainic ridges, but the other lakes are largely in plains that are slightly below the neighboring districts, partly morainic and partly plain.

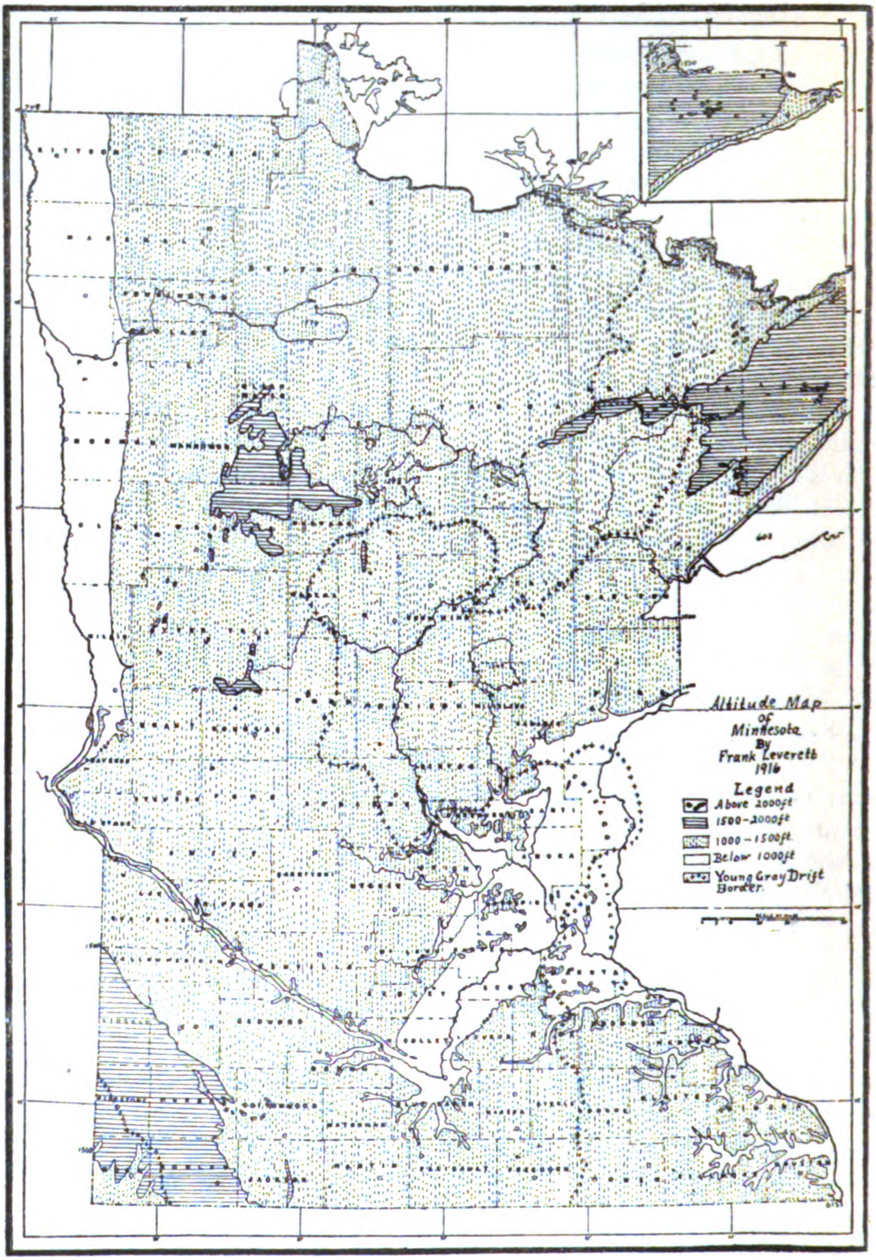


FIGURE I. ALTITUDE MAP OF MINNESOTA

EXPLANATORY NOTE, FIGURE I

This map shows the great extent of land in Minnesota standing between 1,000 and 1,500 feet above sea level, as well as the distribution of the higher areas and of areas standing below 1,000 feet.

It shows also the effect of low areas in favoring the movement of the latest invasion of ice from the north, that which deposited the young gray Keewatin drift, as well as the effect of the high areas in checking the movement. The great axial movement of the ice was through the low-lying Red River basin, much of which is below 1,000 feet, and thence down the Minnesota valley to the great bend at Mankato over a plain much of which is below 1,100 feet. The thumb-like offshoot of the ice, in a lobe extending from Wright and Hennepin counties northeastward across Anoka, Isanti, and Chisago counties, into the edge of Wisconsin, was apparently induced by an exceptionally low area, largely below 1,000 feet, over which it passed. In northern Minnesota the ice passed over the relatively low land, 1,200 to 1,300 feet, along and near the Mississippi River in Cass and Itasca counties, into the St. Louis River basin in St. Louis County, and down the Mississippi in Aitkin County; but it was so checked by higher land, 1,500 to 1,750 feet, in Clearwater, Becker, and Hubbard counties, that it could there reach only southeastern Hubbard and neighboring parts of Cass and Wadena counties. The Mesabi Range also held the ice border back nearly to the western edge of St. Louis County while it pushed eastward some distance in St. Louis County, both north and south of the range.

The topography also influenced ice movement in the northeast part of the state. There was a strong movement of ice southwestward through the Superior basin, with its northwest border only a few miles back from the shore on the high land, much of which stands 1,500 feet or more above the sea. This high land was largely covered by ice moving southward from the neighboring part of Canada. The relations of this ice movement to that in the Superior basin, as well as to that which covered western Minnesota is set forth in the discussion of the glacial deposits.

SURFACE GEOLOGY

ROCK AREAS

The areas in which rock is so exposed as to render the land untillable are largely in the northeast quarter of the state, or along valleys in the southeast quarter. The northwest quarter is estimated to have less than 10 square miles of bare rock outcrop, and the southwest scarcely 100 square miles. It is doubtful if there is an area of 1,000 square miles in the entire state in which the plow would generally strike into rock ledges. The rock areas thus form a much smaller percentage of the state than the lake areas. The rock areas of the northeast part are chiefly rock bosses standing above the surrounding land, but the beds of the streams that lead directly down to Lake Superior are also usually on rock ledges. Among the rock knobs are some depressions covered only with moss and peaty material, glacial material being scanty, but ordinarily some glacial material is present and nearly all the land has soil enough over the bedrock to support a rich forest growth. Many of the knobs preserve the smooth surface left by the scouring effect of the ice sheet and are nearly destitute of vegetation. But certain others have become disintegrated to a depth of several inches or even to several feet from the surface and are supporting growths of vegetation of considerable density.

The rock areas of the southwest part of the state are largely of Sioux quartzite which in places comes to the surface over areas of several square miles. The rocks have scarcely enough soil over them to support the scanty vegetation. There are a few small areas of granite knobs along the Minnesota valley from Big Stone Lake down to New Ulm. In the driftless area and part of the drift-covered area in southeastern Minnesota, rock ledges of limestone and sandstone outcrop along the steep slopes of the valleys, often forming walls of considerable height. Rock is rarely exposed along the stream beds and valley bottoms. The uplands and the higher parts of the slopes of the valleys even in the driftless area usually have several feet of residuary clay and also a coating of loess or wind-deposited silt loam covering the rock formations and rendering the land tillable.

THE EARTHY MANTLE

GENERAL STATEMENT

The variety of earthy, sandy, and gravelly unconsolidated deposits which cover the rocky floor of Minnesota were formed or deposited by different agencies and at different times. They may be grouped as follows:

First. Residuary material.
Second. Wind deposits.
Third. Glacial deposits.
Fourth. Stream deposits.
Fifth. Lake deposits.

RESIDUARY MATERIAL

The residuary material, as its name implies, has been left as a residue during the breaking down or decay of the surface rocks through weathering and solution. On limestones it is usually a dark, reddish brown, gummy clay, but on sandstones and crystalline rocks it is usually granular and loose-textured. There is but a small part of Minnesota, chiefly in the southeastern counties, where residuary material is within reach of the plow. It occurs there on the upper part of the slopes of the valleys and on the narrow upland strips between valleys, but it is usually covered by loess.

WIND DEPOSITS

Loess.—The wind-deposited material known as loess is largely a fine silt loam, which forms the surface in an area in the southeast part of the state embracing much of Goodhue, Olmsted, Wabasha, Winona, Fillmore, and Houston counties and parts of Mower, Dodge, Rice, and Dakota counties. It covers a small tract in the southwest part of the state. In the southeastern counties it rests in part on glacial drift deposits and in part on the residuary clay and rock formations of the driftless area. In the southwestern part it covers glacial deposits. In the southeast district its border is very irregular, there being long strips of loess-covered land projecting westward or northwestward into the region free from loess, and also long strips free from loess extending eastward into the loess-covered tracts. The condition there is such as might result from the presence or absence of vegetation giving different degrees of protective power from the wind; areas with dense vegetation being able to hold dust that settled from the atmosphere while bare ones allowed it to be gathered up and carried on.

Wind-blown sand.—Wind-blown sand is also an important deposit. It embraces a district east of the Mississippi from Minneapolis up to Brainerd. It is narrow above St. Cloud, but below that city extends eastward to the St. Croix River. The sand does not, however, cover the entire surface in this area. Where present it rests upon glacial deposits. It has low ridges seldom 20 feet and usually 10 feet or less in height. There is more or less wind-drifted sand in the sandy parts of the St. Louis River drainage basin, but it is sparingly developed compared to that in the district between the Mississippi and St. Croix rivers. Wind-blown sand occurs also in Aitkin County in the vicinity of McGregor and also in the northeastern part of the county in island-like tracts that are surrounded by marshes. There are numerous small areas of such sand scattered over the state, some of them being along the shores of the glacial Lake Agassiz.

GLACIAL DEPOSITS

The glacial deposits as shown in Figure 2 extend over the entire state except eastern Winona County and the greater part of Houston County, which are in the driftless area of the upper Mississippi. They underlie the wind-deposited sands and much of the loess area. They also underlie stream deposits and lake sediments. The glacial deposits are separable into till or bowlder clay in which stones, clay, and sand are closely commingled; and into sand or gravel beds which show some assorting and bedding by water action. The percentage of stony material varies greatly and the matrix also shows variations from compact clay to loose sand. These variations are to be expected in a deposit that had been formed from the dirt and stones included in an ice sheet. Every observing farmer has probably noted and perhaps speculated upon the cause for these variations in the drift deposits which form the basis for so large a part of the Minnesota soil. The assorted sand and gravel beds are largely due to waters escaping from the melting ice and many of them may be traced up to a moraine which marked the position of the ice border at the time they were laid down. They show a decrease in coarseness in passing away from the edge of the moraine, the coarse material having been dropped close to the edge of the ice and only the fine carried to a great distance outside.

The glacial deposits also show some variations that relate to the kind of rock formations over which the ice passed. Thus, the northeastern portion of the state has a rather stony drift from the volcanic and hard crystalline rocks of that region. This stony material was carried as far south as Dakota County and forms the red drift of eastern and northeastern Minnesota. As indicated below, the red drift is the product of more than one ice sheet. The western and southern parts of the state have a large amount of clayey drift material with limestone pebbles imbedded. This material was gathered by this ice as it passed in its southward course from the shales and limestone of southern Manitoba, into the area of granite and other crystalline rocks. These clayey and limy deposits form what is known as the gray drift of Minnesota, and the ice sheet which formed it, as the Keewatin ice sheet.

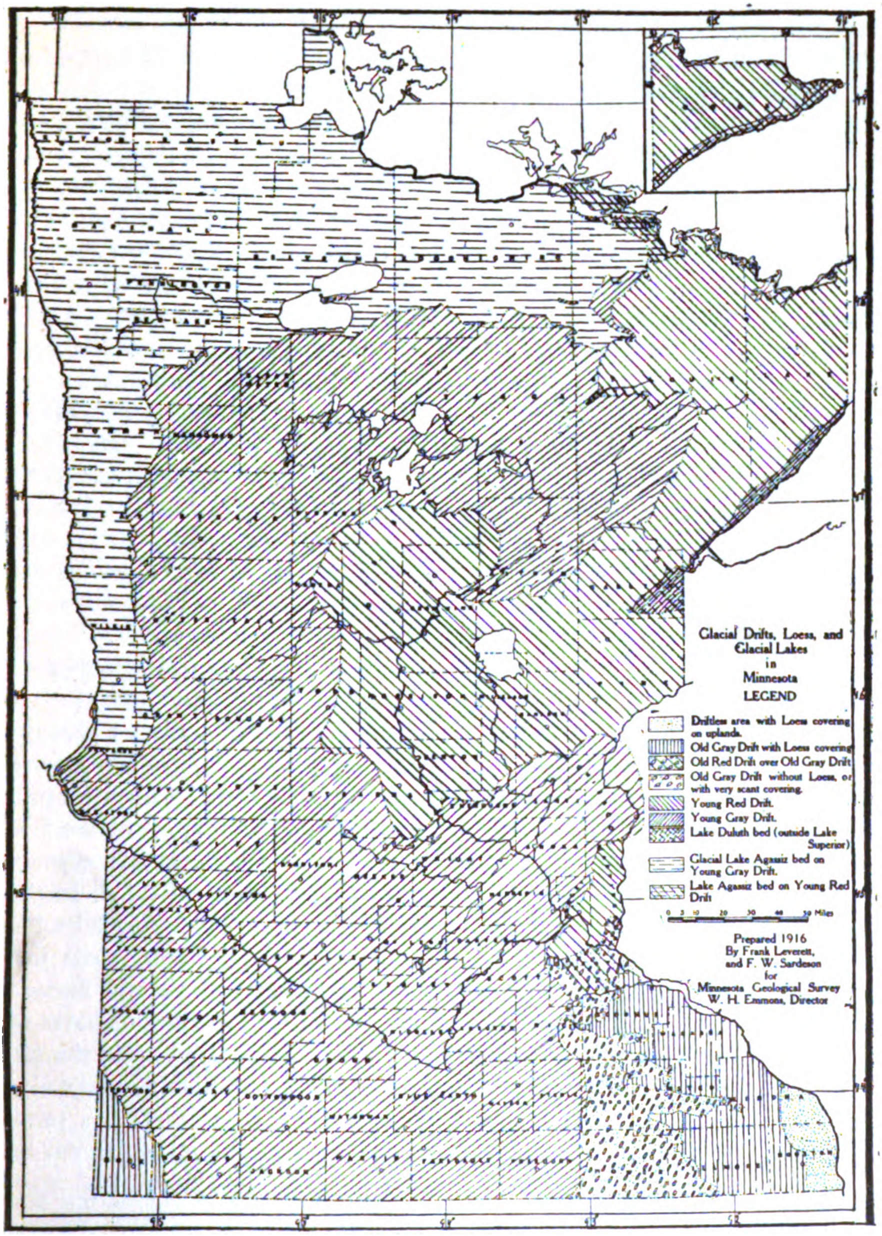

Glacial Drifts, Loess, and Glacial Lakes in Minnesota
LEGEND
Driftless area with Loess covering on uplands.
Old Gray Drift with Loess covering
Old Red Drift over Old Gray Drift
Old Gray Drift without Loess, or with very scant covering.
Young Red Drift.
Young Gray Drift.
Lake Duluth bed (outside Lake Superior)
Glacial Lake Agassiz bed on Young Gray Drift.
Lake Agassiz bed on Young Red Drift
0 5 10 20 30 40 50 Miles
Prepared 1916
By Frank Leverett,
and F. W. Sardeson
for
Minnesota Geological Survey
W. H. Emmons, Director

FIGURE 2. MAP OF GLACIAL DRIFTS, LOESS, AND GLACIAL LAKES IN MINNESOTA

STREAM DEPOSITS

The stream deposits, being restricted to the valleys, are of limited area, though in such valleys as the Minnesota and Mississippi they are locally several miles in width and form important agricultural belts. On the Minnesota and the part of the Mississippi below the confluence with the Minnesota the deposits made by the rivers are sand or silt. On the Mississippi above the mouth of the Minnesota the deposits range from sand to coarse cobble and bowlders in correspondence with the swiftness of the stream. On nearly all the tributaries of the Mississippi and Minnesota the streams are able to carry coarse as well as fine material. Along the Red River a considerable amount of fine clay and clay loam has been deposited in seasons of flood on the plains outside the immediate river channel. The deposits made by glacial streams or those which had their sources at the edge of the ice and were receiving much of their water from the melting ice, now appear usually as terraces along the valleys above the limits of floods. From the fact that the glacial rivers were of greater volume these deposits are generally composed of sandy and gravelly material somewhat coarser than that carried by the present rivers.

LAKE DEPOSITS

The lake deposits consist of fine sediments washed into the deep parts of the lakes, and sandy and pebbly deposits washed up and formed into beaches along the shores. In parts of the lakes where the glacial deposits which they covered were pebbly and the water was shallow enough for wave action, there was a concentration of stony material by the washing-out of the finer material. By this process considerable areas of the bed of Lake Agassiz were covered by very pebbly beds several inches in depth. They are classed on the soil maps as "lake-washed till." In the narrow strip along the shore of Lake Superior that was covered by the waters of a glacial lake known as Lake Duluth, there is very little fine sediment; gravelly and cobbly beaches were formed at several successive levels, while fine material was washed down into the deeper parts of the basin covered by the present lake. Fine material also covers the old lake plain in Carlton County and a strip on the south side of Lake Superior.

THE GLACIAL FEATURES AND THEIR HISTORY

It has been found through a study of the deposits in Minnesota and neighboring states that the glacial deposits which form so extensive a mantle in Minnesota are the result of more than one invasion of the ice from the Canadian highlands. At each invasion the ice left a deposit of drift gathered partly from Canada and partly from the deposits over which it passed in Minnesota. The advances were so widely separated in time that the drift deposits of one invasion had large valleys cut in them by the action of streams before the next invasion occurred. The later advances failed to reach the limits of the earlier deposits, so they are still exposed to view, and the degree of erosion of the surface of the older can be compared with that on the surface of the younger deposits. It is found that the older drifts have been so greatly eroded and are so ramified by drainage lines that no lakes or undrained basins remain on them, while the younger drift deposits have numerous lakes and undrained basins and also large, poorly drained areas which the streams have not yet reached. It is because they are not covered by the latest drift that Rock and Pipestone counties in southwestern Minnesota, and Goodhue, Dodge, Wabasha, Olmsted, Winona, Fillmore, and Mower counties in southeastern Minnesota have no lakes and basins such as characterize neighboring counties that were covered by that drift.

The invasions of the ice into Minnesota not only took place at different times, but have come from more than one direction at about the same time. In the earlier invasions the greater part of the state was covered by ice coming from Manitoba as shown by limestone fragments and pebbles derived from rock formations of that country which are imbedded in the lower part of the drift over all of the state except its northeast part. The movements in the closing stage of the glacial epoch were more largely from the northeast, but more than half of the state was invaded from the northwest. The ice sheets were as follows: 1. *The Superior lobe of the Labrador ice sheet,* an extension of ice southwestward from the Superior basin nearly to Mille Lacs Lake; 2. *The Patrician ice sheet,* with southward movement from the highlands north of Lake Superior across eastern Minnesota to points a little beyond St. Paul; 3. *The Keewatin ice sheet,* which moved southward through Manitoba and across western Minnesota. After the melting away of the ice that came from the northern highlands, the Keewatin ice sheet extended over some of the ground that ice had vacated. It crossed the Mesabi Range into the St. Louis basin, and also moved northeastward from near Minneapolis into Wisconsin. This advance over earlier drift deposits is known from the presence of a thin deposit of clayey and limy drift containing rock material brought from Manitoba which covers the drift that was deposited by ice coming from the highlands northwest of Lake Superior. The drift from these highlands together with that from the Lake Superior basin forms the stony red drift of eastern Minnesota, while that from Manitoba forms the clayey and limy gray drift which covers almost all of the remainder of the state.

That the ice mass moved in different directions at different times in certain parts of the state is further shown by striations or ice markings on the surfaces of the rock ledges. In the district east and south of the Lake of the Woods a set of glacial grooves or ice markings bears west of south, while a newer set crosses them in an eastward or southeastward direction. The older set was formed by ice moving into Minnesota from the highlands that lie between Lake Superior and Lake Winnipeg, while the younger set was formed by ice moving into the state from Manitoba. In North Minneapolis there are rock ledges on which the glacial grooves have three courses; first, a southeastward course at the time when the old gray drift which came from the northwest was brought in; second, a southward course at a time when the red drift which came from the north was deposited; third, an eastward course at the time when the ice from the northwest advanced over land that had been vacated by the ice which deposited the red drift.

GLACIAL LAKE FEATURES

Minnesota contains parts of the beds of two large glacial lakes: Lake Duluth, which occupied the western part of the Superior basin, and Lake Agassiz which occupied the Red River basin. Lake Duluth covered a narrow strip along the shore of Lake Superior and extended a few miles beyond the west end of Lake Superior into eastern Carlton County, Minnesota. Its highest stages were 500 to 700 feet above the present surface of Lake Superior, there being an increasing height toward the northeast corner of the state. Lake Agassiz extended as far south as Lake Traverse, and thence it discharged past Brown Valley to the Minnesota. Its border is only from 20 to 30 miles east from the North Dakota–Minnesota line from Lake Traverse northward to Polk County. About 20 miles east-southeast of Crookston it makes an abrupt eastward turn and continues eastward past the south side of Red Lake and on across Koochiching County into St. Louis County as far as the valley of Little Fork River. It then turns northward and enters Canada from northeastern St. Louis County. There were several islands in it in northern St. Louis County.

Preceding the development of the large glacial Lake Agassiz there was a temporary ponding of waters in front of the ice in Koochiching, Itasca, and St. Louis counties at a level higher than that of Lake Agassiz, and a discharge of the waters southward across the Mesabi Iron Range into the St. Louis basin along the course of the Embarrass River. With the melting back of the ice border this lake became merged with Lake Agassiz, and its waters then discharged into the Minnesota valley.

In the Crow Wing drainage basin a glacial lake, Lake Wadena, covering much of Wadena County, and parts of Hubbard, Cass, Morrison, and Todd counties, was held up by the Patrician ice sheet, which covered the lower course of Crow Wing River below Pillager. Its outlet was southward from Long Prairie to the Sauk River drainage. Outwash plains near Pillager terminate abruptly at the edge of this lake at an altitude of about 1,300 feet, or nearly 150 feet above the adjacent part of the plain on Crow Wing River that was covered by the lake (see Pillager topographic map). This was the deepest part of the lake. In much of its area the waters were very shallow. This lake area was later encroached upon by the Keewatin ice sheet, so its shore lines are obliterated except along the eastern side. Its outlet has also been filled by gravel deposits from the Keewatin ice sheet for a few miles south from Long Prairie.

There were also two noteworthy temporary lakes in northeastern Minnesota which were not held up by ice barriers, but instead by land barriers along their outlets. When these were cut away the lakes became drained. One of these, named Lake Aitkin by Upham, occupied the plain bordering the Mississippi in Aitkin County and extended a short distance into eastern Crow Wing County. It was drained by the erosion of the Mississippi valley at its lower end just above Brainerd. The other lake, named Lake Upham by Winchell, occupied a considerable part of the St. Louis basin in western St. Louis County. It was drained by the erosion of the St. Louis valley below Floodwood.

Prominent features of the two great glacial lakes, Lake Agassiz and Lake Duluth, are the beaches or ridges of sand and gravel washed up along their shores. The shores of Lake Agassiz stand high and dry above the flat parts of the lake bed between or below them and form excellent lines for highways. For this reason much of the pioneer settlement and travel was along these ridges. They generally stand from 5 to 10 feet above the bordering plains and occasionally from 15 to 20 feet. On the inner or lakeward side they are generally more prominent than on the outer or landward side. This is due in part to the original slope toward the center of the lake, but there is also a tendency for a lake to eat back into the bordering land and throw its coarser material up on the edge of the plain outside; at the same time the fine material is carried in suspension from the shore into the deeper water.

The levels of these glacial lakes were lowered from time to time, partly by the cutting-down of the outlets and partly by an uplift of this region which caused the water to fall away where the land rose. There was also a change of outlet in Lake Agassiz from the southern end to the northern and in Lake Duluth from the southward outlet into the St. Croix River to an eastward outlet into the Lake Huron basin. As a result shore lines were formed at various levels on the slopes of the old lake beds. Because of the gradual lowering of the water level the greater part of the beds of these glacial lakes has at some time been subjected to wave action. This has produced a widespread pebbly coating which is a concentrate from the washing of the surface of the bowlder clay and the carrying-away of its finer material. Where the bowlder clay was sandy, the sand as well as stones remain, but where it was clayey there is often a clear bed of pebbles a few inches in depth covering the clayey till subsoil. The deep part of Lake Agassiz along the borders of Red River received nearly all the fine sediment which was washed out from the till at higher levels. This forms the bulk of the rich black clay and clay loam of the Red River basin. At its eastern border, fifteen to twenty-five miles from Red River, there is a transition to sand. This is succeeded within two to five miles east by stony sandy deposits which seem to be a glacial material worked over by the lake.

GENERAL SOIL CONDITIONS

Soil is composed of materials derived from the subsoil and mixed with organic matter. Subsoil is the weathered and disintegrated top of the underlying geological formation. For its qualities and composition the soil of a given region therefore depends quite closely upon the nature of the geological formations there exposed. In Minnesota the land mantle of glacial and lake deposits affords a well-mixed and rich supply of materials suited for soil-making. This is particularly true where it consists of till or bowlder clay in which all classes of material are loosely but thoroughly mixed. This contrasts with soils in which there is too much uniformity and which, when of water-washed sand or gravel, are often deficient in fine material. On the other hand, the loess and the lake silts, though of somewhat uniform texture, make rich soils because of the variety of finely divided minerals which they contain.

The soil and its productiveness depend largely upon the drainage conditions. A soil of clay or clay loam over gravel or loose sand suffers in time of deficient rainfall, while in wet seasons a soil resting upon heavy clay may be drowned out unless surface drainage is perfectly adjusted. For this reason the geologic formation underlying a soil is of great importance. Soil underlaid by limestone, by loess, or by a till consisting of a light clay, or a heavy loam will stand great variation in rainfall and still be highly productive. In some parts of the state the surface drainage is naturally well developed, while in other parts it needs to be greatly supplemented by tile draining or surface ditching.

In the Driftless Area the drainage on the uplands is everywhere complete, for nearly every acre slopes toward some drainage line. In the old drift also there are few undrained areas and tiling or surface ditching is seldom necessary. In the young drift there are many basins, and undrained depressions and drainage lines are not well distributed over the surface. Except, therefore, where the material is loose enough for the rainfall to be absorbed completely the young drift areas need considerable ditching and tiling. In the bed of Lake Agassiz, although basins and depressions are rare, there are wide areas where the surface is very flat and extensive and systematic tiling or ditching is required to keep the land from being flooded.

VEGETATION

The condition of the soil depends to some degree upon the character of the vegetation which has covered it. In prairie districts there is a more uniform exposure to weathering agencies than in forested districts and consequently a more uniform soil is developed on a given deposit. On the whole, leaching of lime seems to be less rapid on prairies than in forests so that in the newer drift limestones are often present at the surface in prairies, but in the forested areas limestones are usually dissolved out to a depth of some inches and often to some feet from the surface. On the older drift the limestone is generally removed to a depth of several feet both in prairie and forest, but the leaching is perceptibly deeper in the forested areas. The rate of erosion and removal of soil is more uniform in prairie than in forested tracts. It takes more force to dislodge the trees than the grassy vegetation on hillside slopes, and erosion in the forests is likely to become concentrated in occasional gullies, whereas on prairies there are many small channels developed on every hillside which serve to break it down rapidly. On the whole, therefore, erosion is greater but leaching is less in prairie than in forested areas.

The forests occur only on protected slopes in much of southern Minnesota and are absent from such slopes in much of the western part of the state (Figure 3). In the central and northeastern parts they cover plains or uplands as well as valley slopes. The muskegs, which have a scanty forest growth, are developed chiefly in the northern half of the state and chiefly within the forested area.

WEATHERING

There are parts of the newer drift in which fresh material is close to the surface so that they can scarcely be said to have a subsoil different from the drift sheet as a whole. There are also places on valley slopes in the older drift where unweathered material is close to the surface, because erosion keeps pace with the weathering of the drift. At most places, however, the older drift has a mantle of weathered material several feet in thickness, while that of the younger drift is only one or two feet thick. In this the feldspar and other minerals are disintegrated and made ready for plant food.

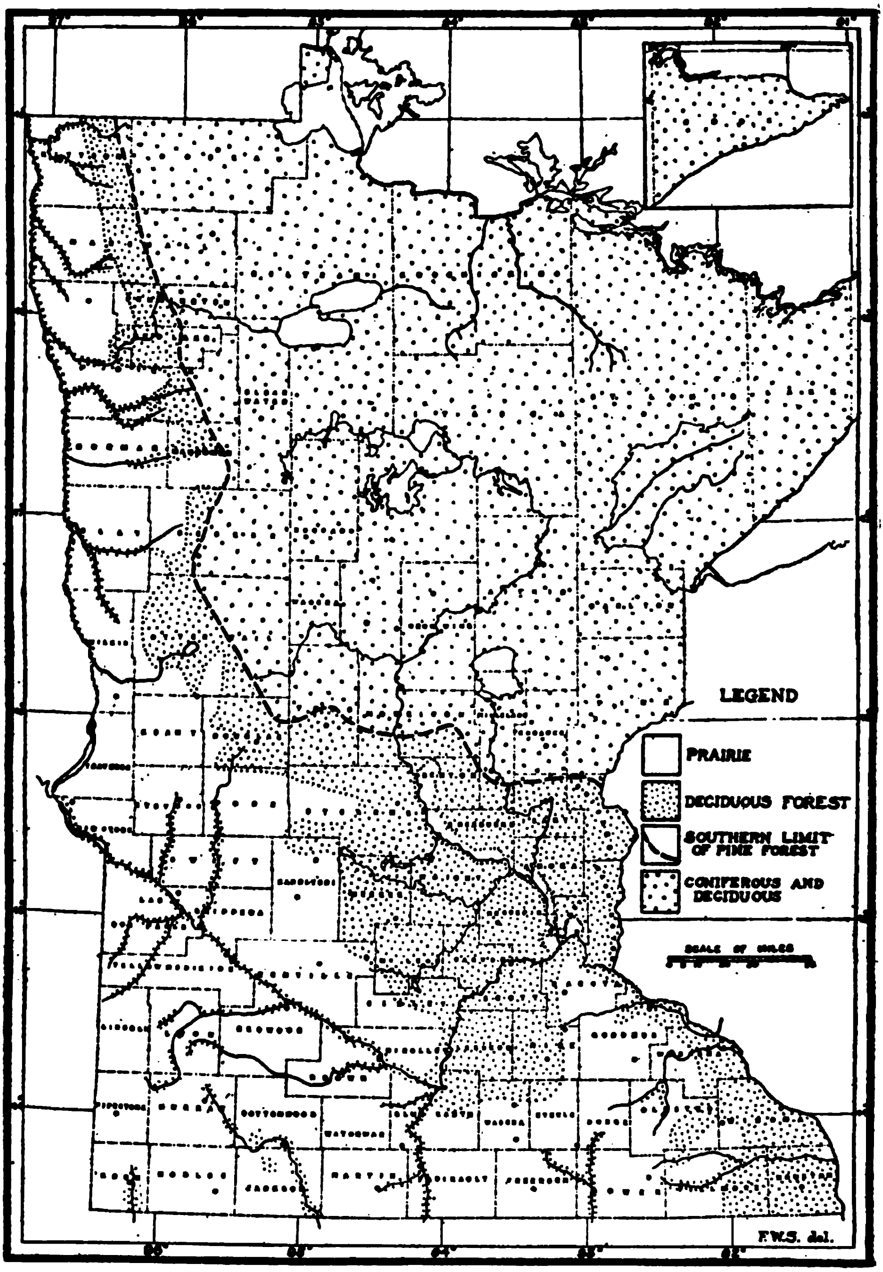


FIGURE 3. MAP OF MINNESOTA SHOWING DISTRIBUTION OF FOREST AND PRAIRIE. (AFTER MAP BY WARREN UPHAM AND BY FREDERIC K. BUTTERS)

Weathering in the loess-covered areas is moderately deep, as it is in the older drift. The entire deposit of loess, however, is of fine texture and is found to be very fertile from top to bottom.

LIME

While most of the soils of the northwestern part of the state seem abundantly supplied with lime, it is probable that some of the more sandy ones would give a sufficiently greater yield of certain crops to make it profitable to purchase some form of lime if this could be obtained at a low price. Usually when a soil needs lime, it is advisable to apply one ton or more of ground limestone or marl per acre. If this has to be shipped any considerable distance, the freight charges may greatly exceed the cost of the material on board of the cars at the point of shipment. For this reason it is important to locate a supply as near as possible to the place where it is to be used.

Lime occurs abundantly in two forms in Minnesota: as bog-lime or marl, and as limestone. The marl is unconsolidated and easily pulverized. It needs no crushing or grinding. Limestone is consolidated and must be crushed or ground for use on fields.

Marl is found in Minnesota in many lakes and under some bogs that have been lakes. It is of most frequent occurrence in the central and north central part of the state. It lies always in low wet ground and can be found, as a rule, only by boring or ditching. It is a soft, white or gray, chalky material. Since it needs no crushing or grinding, the cost of the marl is in the finding, ditching and draining, or drying of it. Deposits from 1 to 10 feet in thickness and covering from 1 to 100 acres are known to be of common occurrence.

Limestone formations outcrop in the bluffs along the Mississippi and its tributaries in southeastern Minnesota. The formations lie horizontally and are of wide extent, or practically continuous for many miles. Limestone formations 100 feet or more thick extend along the valleys from the southeastern corner of the state to Stillwater, Minneapolis, Mankato, Austin, and intermediate points. An inexhaustible supply of limestone is easily found in outcrops that are high, so that quarrying, crushing, and loading can all be done in a down-hill direction, the cost of production being thereby lessened.

EFFECT OF FIRES

There are large areas in Minnesota which have been swept by forest fires, and these fires have destroyed much of the accumulated leaf mold. In sandy areas the destruction of the leaf mold may have reduced somewhat the productiveness of the land, for the leaf mold acts as a mulch to prevent the drying out of the soil. But in clayey areas there seems to have been very little reduction of the fertility. The leaf mold in such places, however, when turned under has a beneficial effect in loosening the stiff clay. A large area of clay land in the Little Fork drainage basin in St. Louis and southeastern Koochiching counties was burned over some fifty or more years ago, according to statements of the Indians, and the leaf mold was almost completely destroyed. A heavy growth of poplar has sprung up on the drier parts instead of the mixed hardwood that had occupied the land, while the wet areas have a fresh stand of spruce. This district is being rapidly cleared and is producing exceptionally good crops. The forest fire near Hinckley in Pine County, which occurred about twenty-five years ago, swept over an area chiefly of till much of which is loose-textured. This had a similar effect in changing the forest from mixed hardwood and pine to poplar. This area is now one of marked agricultural fertility adapted to a variety of crops. The principal damage by fire in this state, both past and prospective, seems to be in the destruction of peat in the bogs. In such cases there is not only the loss of a valuable fuel, but the land is left in a rough state ill-suited for cultivation.

CHAPTER II

CLIMATIC CONDITIONS OF MINNESOTA

By U. G. Purssell

Director of the Minnesota Section of the United States Weather Bureau

INTRODUCTION

The agriculture of any region is controlled by its climate. In some parts of the world temperature is the main factor in determining the limits of growth of certain kinds of crops; in others it is rainfall, and in still others it is the amount of sunshine. All of these factors are important in influencing the crop yield even in districts where the general climatic conditions are satisfactory for the growth of plants. In Minnesota these elements are so favorable that a majority of the crops common to the temperate zone may be successfully grown, and a failure of all the important crops is very rare even over a small portion of the state.

Rainfall is an important factor for most crops in the state, because the proper amount of water in the soil at the critical period of development of the plant is necessary to produce a large crop. The length of the growing season also is important and probably no other factor in the study of climate from the standpoint of the agriculturist should be given more consideration. This is the key to an actual knowledge as to the possibilities of success or failure in the production of crops since in parts of the state crops are menaced by frost at some period of their growth, whereas sunshine and moisture seldom vary in Minnesota beyond safe limits.

The factors which determine the climate of any area are the relative distribution of land and water, the topography of the land surface, and the situation of the area in question with relation to the general movement of the cyclones and anti-cyclones.

The position of Minnesota at the center of North America gives it a climate that is largely continental. In continental climates the temperature extremes are greater and the humidity and rainfall generally less than at places near large bodies of water, such as border on the Atlantic, Pacific, and Gulf coasts of the United States. The effect of winds from great bodies of water is to equalize temperatures of lands near by and to lengthen materially the crop-growing season. This is particularly true of the country in the vicinity of Lake Superior, where the influence of that great inland sea in modifying the cold anti-cyclones gives to that section a more equable climate than would otherwise obtain in that portion of the state. The summer temperatures are likewise modified and people from long distances inland in steadily increasing numbers are establishing summer homes about the lake, to which they are attracted during the hot summer months. There are more than 7,000 small lakes scattered throughout the state and these have a material local influence in modifying the heat of summer and give comfort to thousands of residents on their shores.

Monthly and annual reports of temperature, rainfall, snowfall, etc., have been published for a large number of regular and coöperative stations in Minnesota since 1895. Recently three special section reports have been issued by the United States Weather Bureau giving monthly and annual precipitation totals for all points in the state with a record of ten years or over, together with average temperatures and other data. In these reports the more important facts from all portions of the state are tabulated and the comparative climatic conditions of the different sections graphically shown.

GENERAL CLIMATIC CONDITIONS

Minnesota is in the path of a large proportion of the low-pressure areas which move across the United States from west to east. These areas move at an average speed of 600 miles in twenty-four hours and are preceded by southerly winds and higher temperature and followed by northerly winds and lower temperature. They are usually accompanied by cloudy weather and precipitation; each storm causing an average of from one to two rainy days as it crosses the state.

As there is an average of almost two of these storms each week with fair weather periods between, it follows that the changes in weather conditions are rather rapid. One or two days of stormy weather preceded by fair weather and followed by clearing and lower temperatures to be repeated in turn, make up the usual routine for the week. However, Minnesota is so far from the coast that damaging ocean storms lose much of their severity before reaching its borders.

The northwestern cold waves pass across the state and send their health-giving winds into all parts, and yet they are frequently not so severe as they are in some of the plains states in the same latitude or even farther south.

Temperature.—The average annual temperature of Minnesota for the period 1895 to 1913 inclusive, is 41.7°, as shown in Table I and graphically by Figure 4. The highest annual mean temperature, 43.9°, occurred in 1900, and the lowest, 39.9°, in 1912. The departure of the average temperature of any year from the normal may readily be deter-

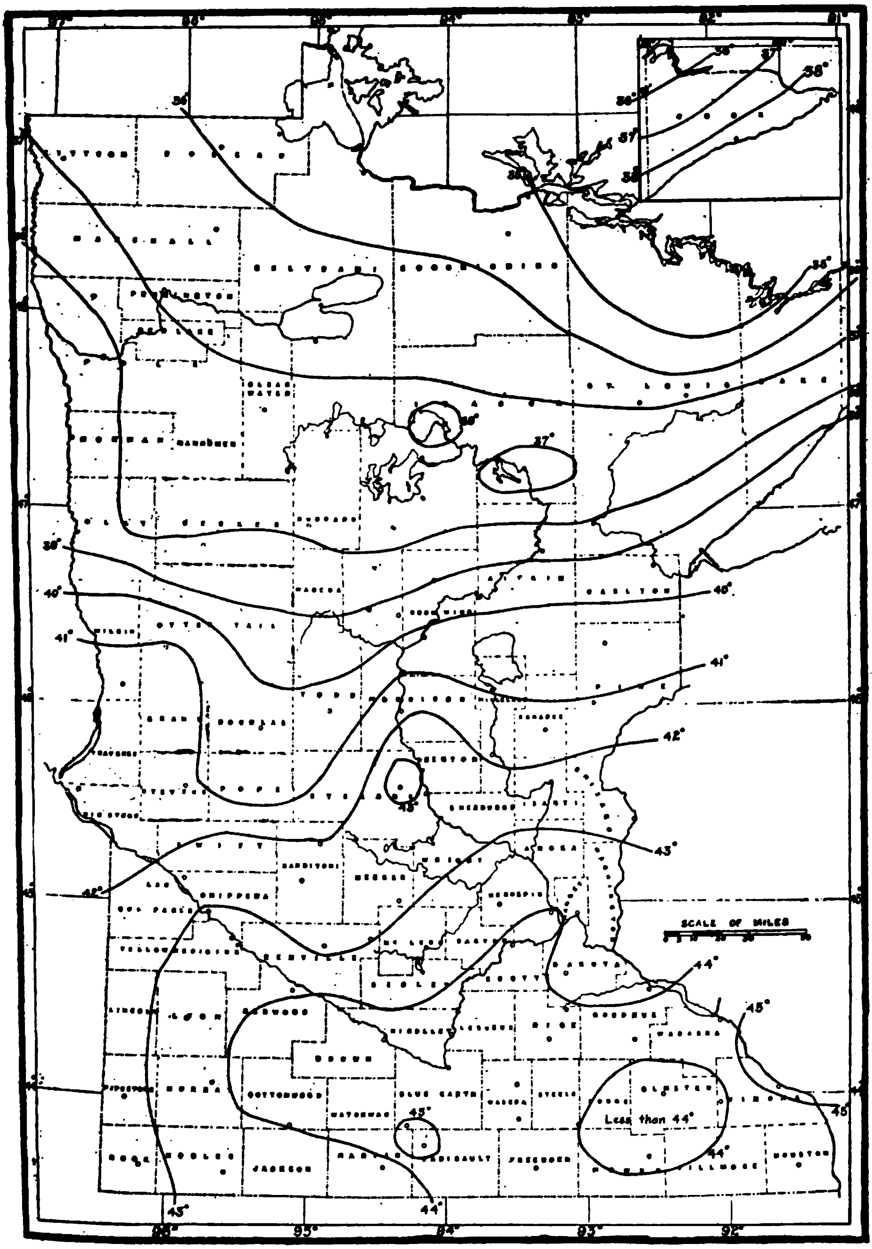


FIGURE 4. MAP SHOWING MEAN ANNUAL TEMPERATURES OF MINNESOTA (DEGREES FAHRENHEIT)

mined by comparing the yearly average with the mean at the foot of the column.

Table I. Monthly and Annual Mean Temperature for Minnesota (Degrees Fahrenheit)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1895	.....	.....	.....	49.9	56.9	64.6	67.8	67.4	61.5	41.4	27.8	18.3	.....
1896	12.3	17.9	21.4	44.5	60.9	66.5	69.9	67.9	54.3	42.4	18.0	20.3	41.6
1897	7.2	15.3	20.7	43.7	55.2	62.5	71.6	64.2	65.3	50.0	26.6	12.3	41.2
1898	18.3	16.4	30.3	43.5	55.6	67.0	69.8	66.9	60.6	42.9	26.6	11.9	42.2
1899	9.9	4.5	14.7	44.0	55.1	65.4	70.2	69.1	56.4	49.0	39.6	17.9	41.2
1900	18.4	5.2	23.4	49.5	59.9	66.8	68.8	74.3	58.2	55.1	25.4	18.6	43.9
1901	13.2	10.0	27.3	46.7	58.2	65.5	74.7	69.8	57.3	49.2	28.8	13.0	42.8
1902	15.9	15.5	34.0	42.6	57.0	61.3	69.7	65.2	55.2	47.1	33.3	12.6	42.6
1903	11.3	10.6	29.6	43.3	55.7	62.3	67.2	63.6	55.5	46.1	27.3	9.8	40.3
1904	4.5	2.3	24.8	38.8	55.4	63.2	66.0	64.9	57.4	47.4	36.7	16.7	40.1
1905	5.6	8.9	33.7	42.0	52.6	63.0	67.3	68.9	61.9	43.5	33.1	20.6	41.5
1906	17.0	13.8	20.6	47.9	53.7	63.7	68.3	68.7	63.3	45.7	30.7	15.9	42.0
1907	3.8	14.8	28.7	34.7	45.5	63.3	68.2	66.1	55.9	45.4	31.7	21.3	40.1
1908	16.4	17.9	26.4	45.2	53.9	62.5	69.4	65.5	64.2	47.0	33.8	17.5	43.4
1909	10.5	13.7	26.1	35.8	53.2	65.0	69.2	70.9	58.7	44.7	33.8	10.0	41.0
1910	11.8	7.5	41.7	48.0	51.6	67.8	70.6	65.8	58.4	50.8	25.3	14.7	42.8
1911	5.4	16.6	32.7	42.7	59.8	69.7	68.2	64.0	56.7	43.4	20.2	19.4	41.6
1912	—6.7	10.6	19.8	45.5	55.9	62.5	68.5	63.9	57.2	47.5	33.9	20.0	39.9
1913	7.2	8.6	20.4	46.4	52.7	67.4	67.3	69.2	58.6	42.7	36.9	26.1	42.0
1914	16.9	2.8	26.6	41.2	57.6	64.6	72.4	66.1	60.0	52.6	33.0	9.0	41.8
Mean....	10.5	11.2	26.5	43.8	55.3	64.7	69.3	67.1	58.8	46.5	30.1	16.7	41.7

The coldest month is January, which has a mean temperature of 10.5°, although the average for February is only 0.7° higher. In a great many instances February has averaged colder than the preceding January. This condition occurred in the seven successive years from 1898 to 1904 inclusive. Average January temperatures are plotted on Figure 5.

July is the warmest month, with an average temperature of 69.3°, although in a few years the mean temperature for June or for August is higher than for July of the same year. Average July temperatures are plotted on Figure 6.

The highest summer mean, 70.0°, occurred in 1900 and 1901 (Table II). The coldest summer was that of 1903, with an average of 64.4°.

The warmest crop-growing season (April to September inclusive) of the eighteen years under discussion was in 1900, when the average was 62.9°, and the coldest was in 1907, with an average of 55.6°.

The warmest winter (December to February inclusive) was in 1907-8, when the mean temperature was 18.5°. The coldest was in 1903-4, with a mean temperature of 5.5°. Table II shows also the warmest and coldest spring and autumn.

In Figures 7 and 8 are shown the highest and lowest temperatures ever recorded in the various counties where records have been kept. From these figures it can readily be seen that the extreme range of temperature is from 110° in Kandiyohi County and Milan, to —59° at Leech Lake Dam and Pokegama Falls. Temperatures above 100° have been recorded in all counties except those about the headwaters of the Missis-

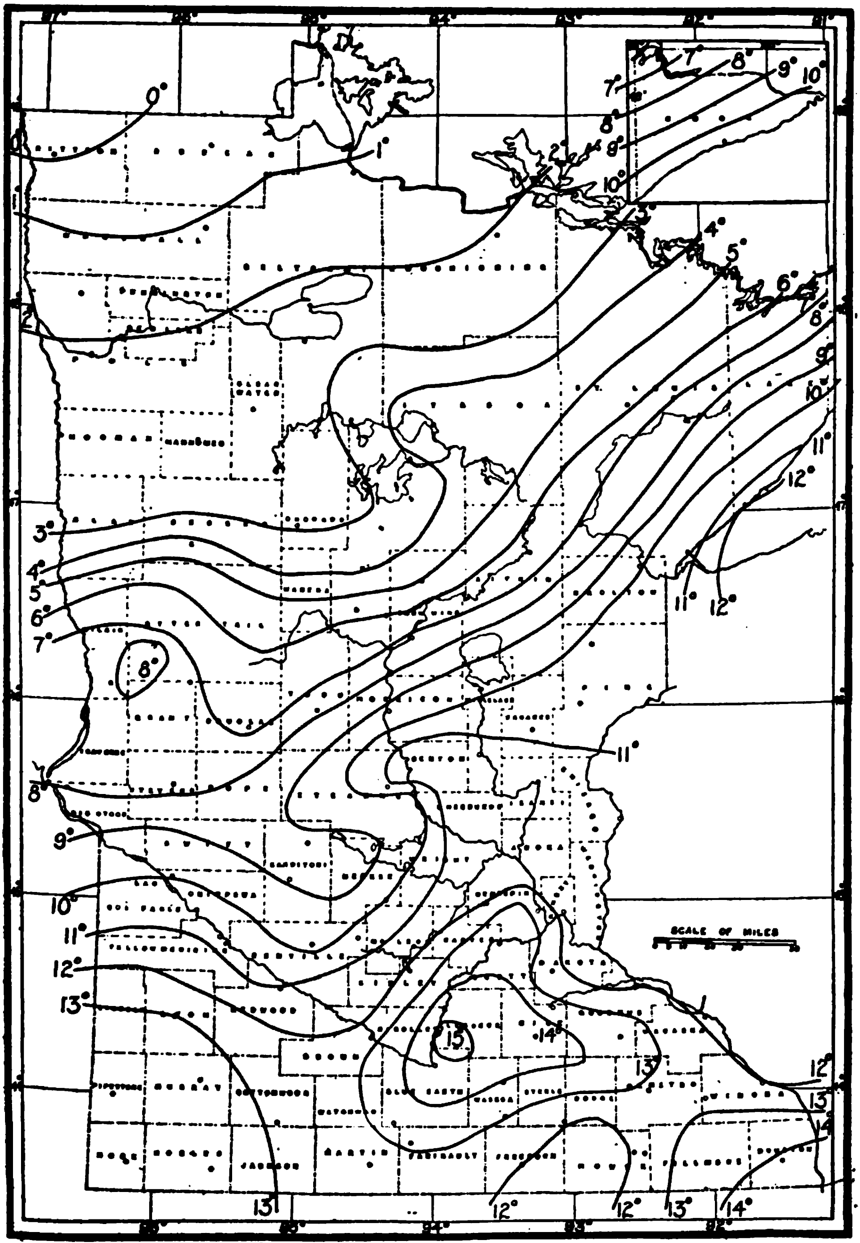


FIGURE 5. MAP SHOWING MEAN TEMPERATURES OF MINNESOTA FOR JANUARY (DEGREES FAHRENHEIT)

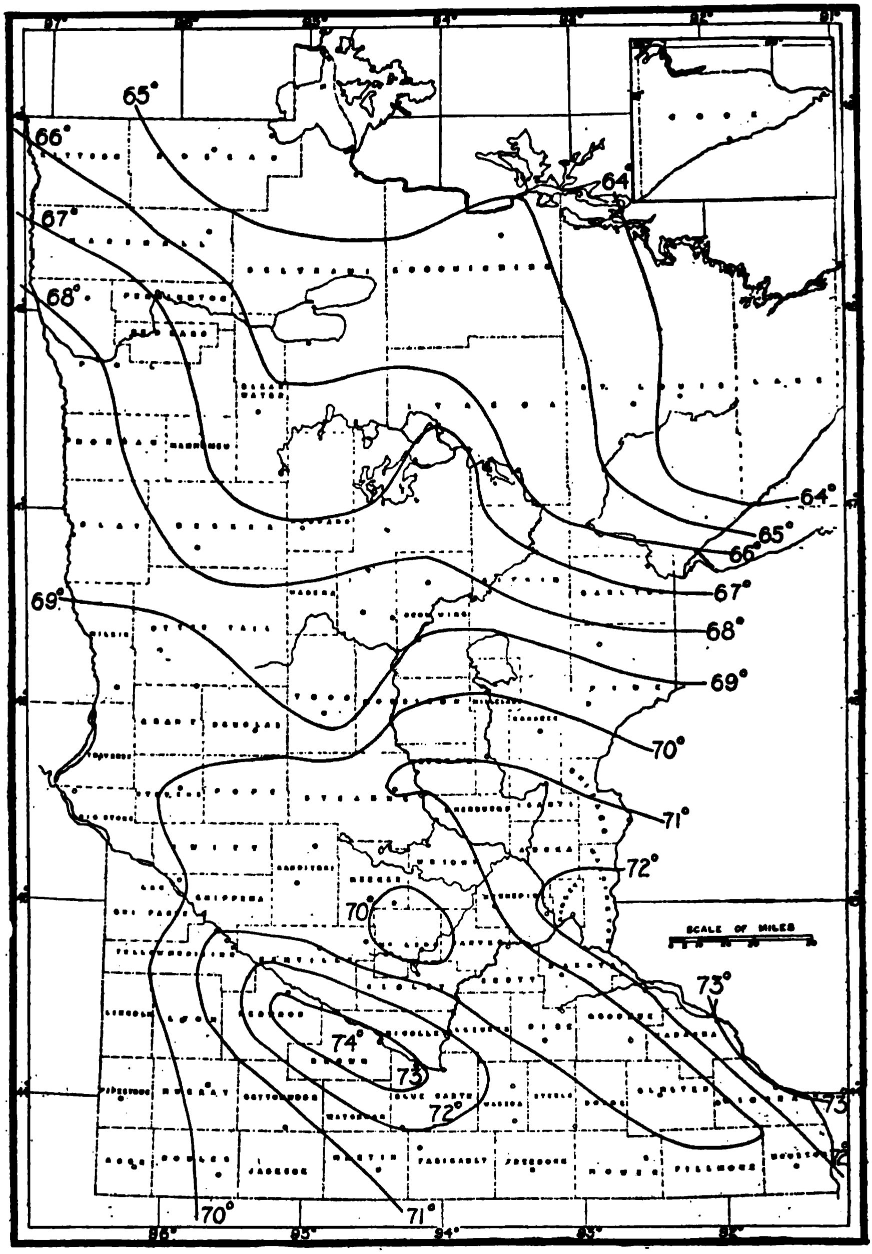


FIGURE 6. MAP SHOWING MEAN TEMPERATURES OF MINNESOTA FOR JULY (DEGREES FAHRENHEIT)

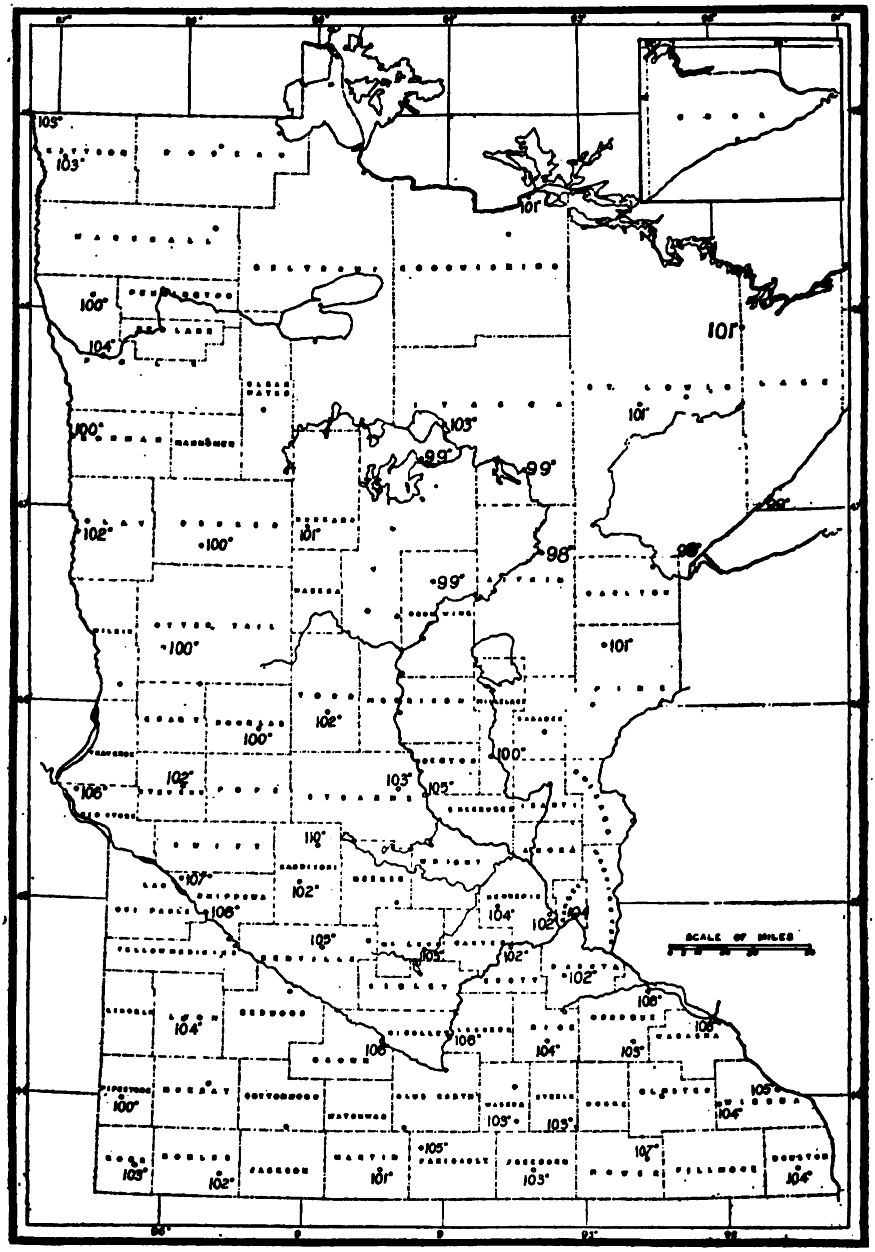


FIGURE 7. MAP SHOWING HIGHEST KNOWN TEMPERATURES IN MINNESOTA (DEGREES FAHRENHEIT)

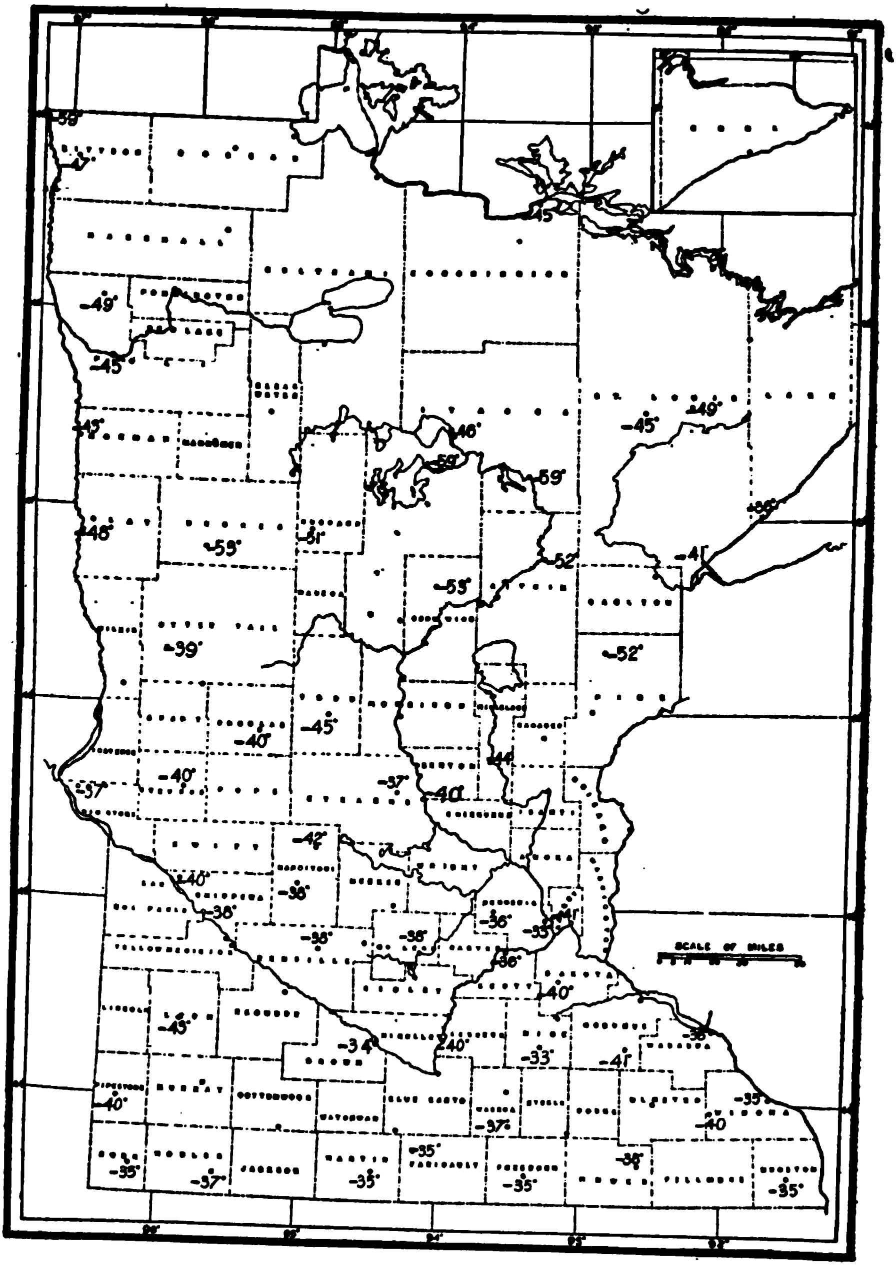


FIGURE 8. MAP SHOWING LOWEST KNOWN TEMPERATURES IN MINNESOTA (DEGREES FAHRENHEIT)

sippi River, and in the country immediately bordering on Lake Superior. Temperatures of —40° have occurred in nearly all northern and central counties and in a few southern counties, but these great extremes do not occur frequently.

Table II. Seasonal Temperatures for Minnesota (Degrees Fahrenheit)

Year	Winter mean	Spring mean	Summer mean	Fall mean	April to Sept. inclusive (crop-growing season)
1895	....	....	....	....	61.4
1896	16.2	42.3	68.1	38.2	60.7
1897	14.3	39.9	66.1	47.3	60.4
1898	15.7	43.1	67.9	43.4	60.6
1899	8.8	37.9	68.2	48.3	60.0
1900	13.8	44.3	70.0	46.2	62.9
1901	13.9	44.1	70.0	45.1	62.0
1902	14.8	44.5	65.4	45.2	58.5
1903	11.5	42.9	64.4	43.0	57.9
1904	5.5	40.0	64.7	47.2	57.6
1905	10.4	42.8	66.4	46.2	59.3
1906	17.1	40.7	66.9	46.6	60.9
1907	11.5	36.3	65.9	44.3	55.6
1908	18.5	41.8	65.8	48.3	60.1
1909	13.9	38.4	68.4	45.7	58.8
1910	9.8	47.1	68.1	44.8	60.4
1911	12.2	45.1	67.3	40.1	60.2
1912	7.8	40.4	65.0	46.2	58.9
1913	11.9	39.8	68.0	46.1	60.3
1914	15.3	41.8	67.7	48.5	60.3
Mean	12.8	41.7	67.0	45.3	59.8

Frosts.—Although frosts have occurred in some portions of the state every month of the year, damaging temperatures are not to be expected during June, July, and August, and they are comparatively rare in the last half of May and the first half of September. Records of ten or more years are available from a large number of places in the state, of which charts have been constructed showing the average date of the last killing frost in spring and the first one in autumn. Using these dates as boundaries, we can mark the average beginning and ending of crop growth and determine the average length of the growing season. All of this information is graphically shown in Figures 9, 10, and 11. By reference to Figure 11 the influence of Lake Superior in lengthening the crop-growing season in its vicinity may be seen; while in the same latitude in the highlands of Hubbard, Becker, eastern Mahnomen, and Clearwater counties the season is twenty to thirty days shorter. The longest season, 160 days, obtains along the Mississippi River from Hennepin County to the southeastern corner of the state, and the shortest, 100 days or less, is in the region of the Mesabi and Vermilion Iron ranges.

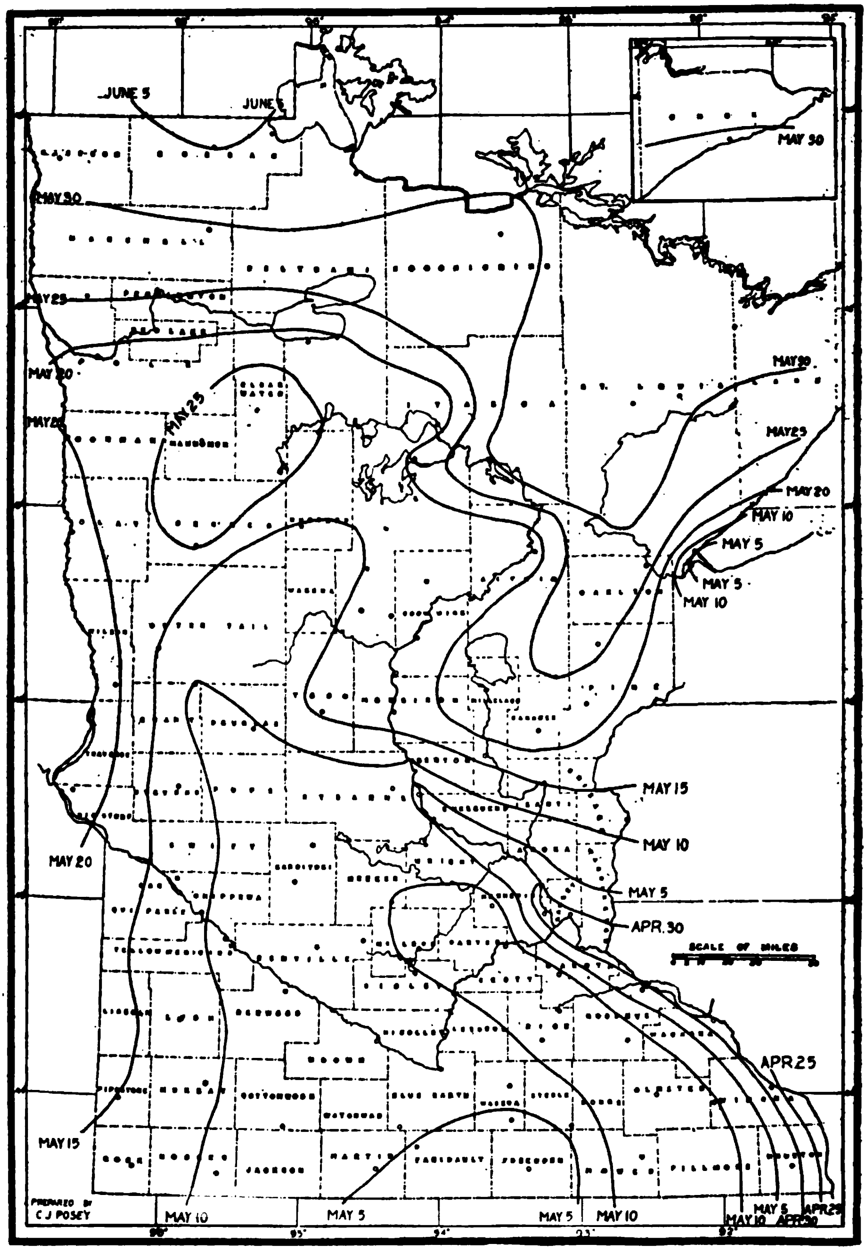


FIGURE 9. MAP SHOWING AVERAGE DATE OF THE LAST KILLING FROST IN SPRING IN MINNESOTA

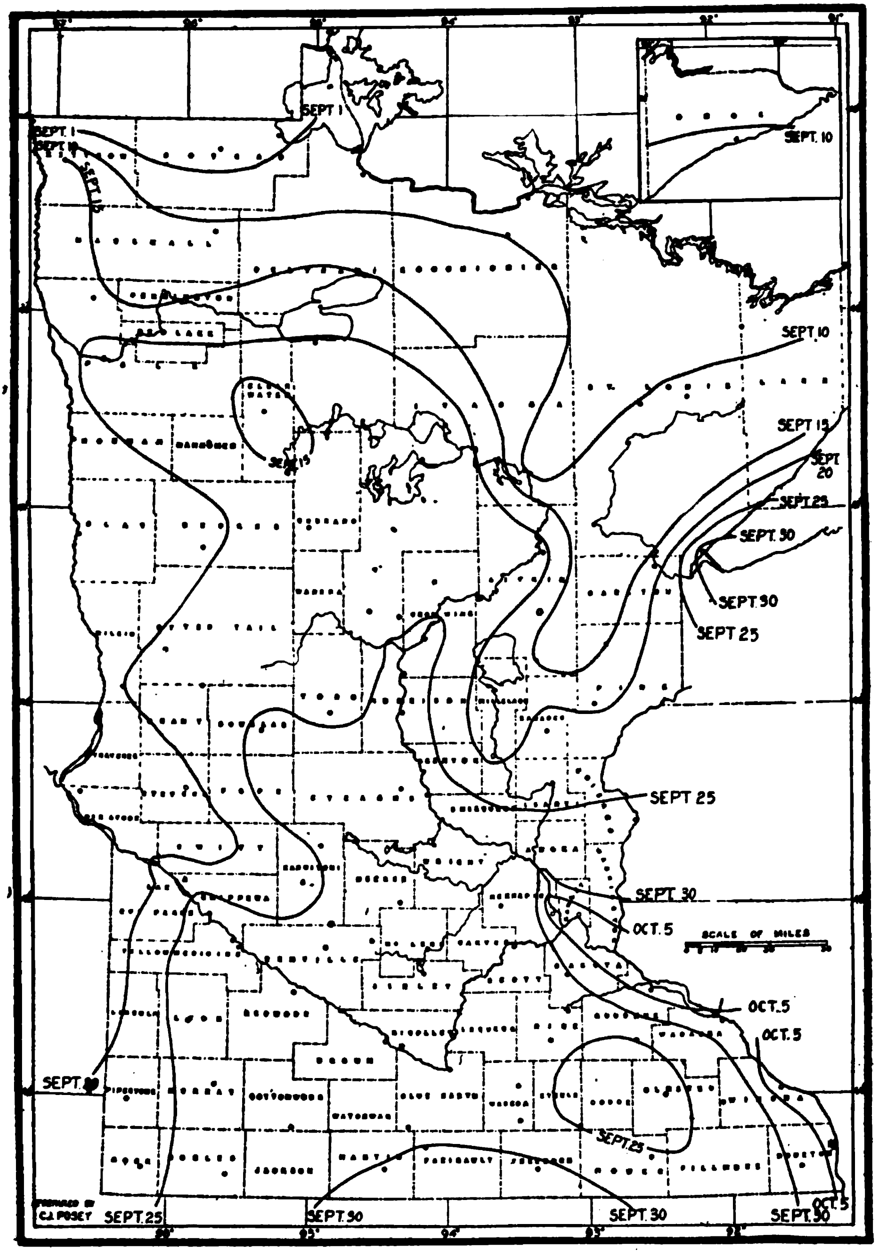


FIGURE 10. MAP SHOWING AVERAGE DATE OF FIRST KILLING FROST IN AUTUMN IN MINNESOTA

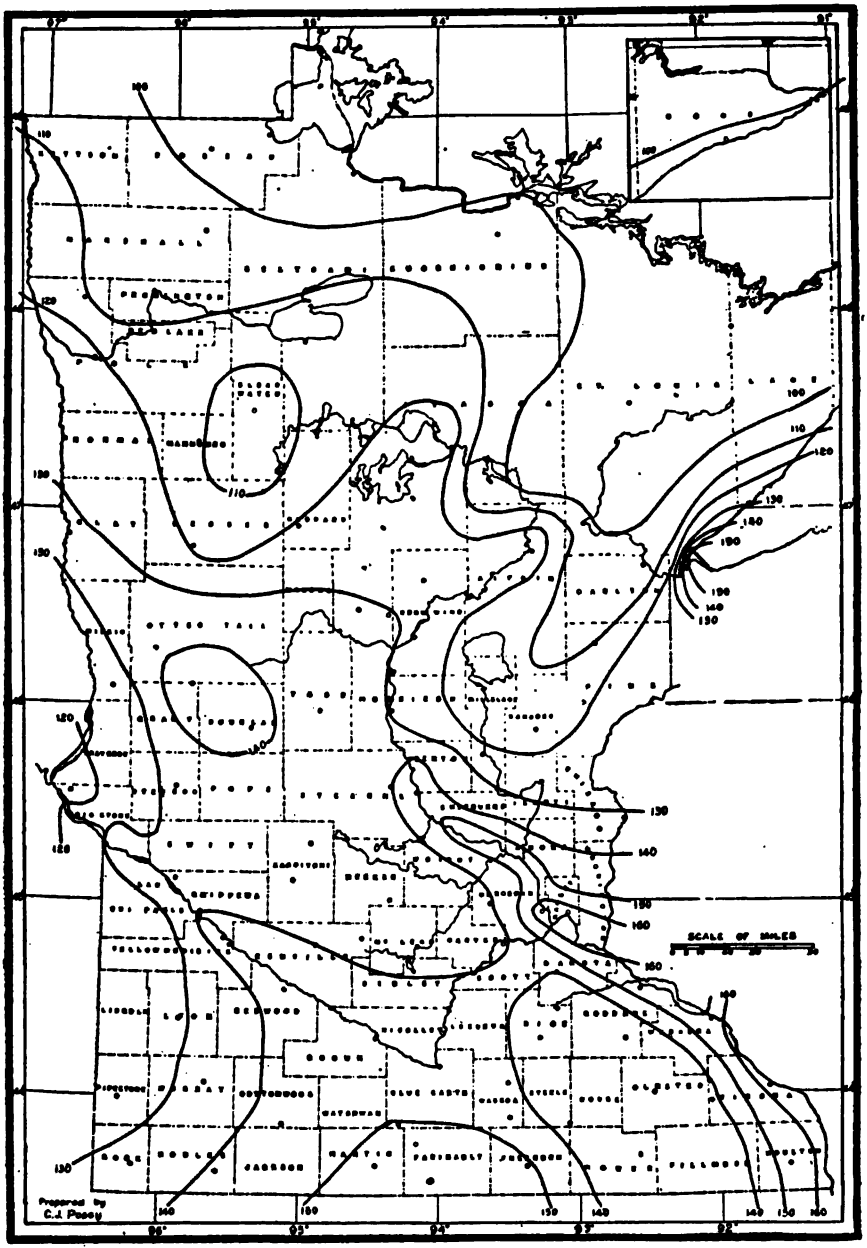


FIGURE II. MAP SHOWING NUMBER OF DAYS OF THE AVERAGE CROP-GROWING SEASON IN MINNESOTA

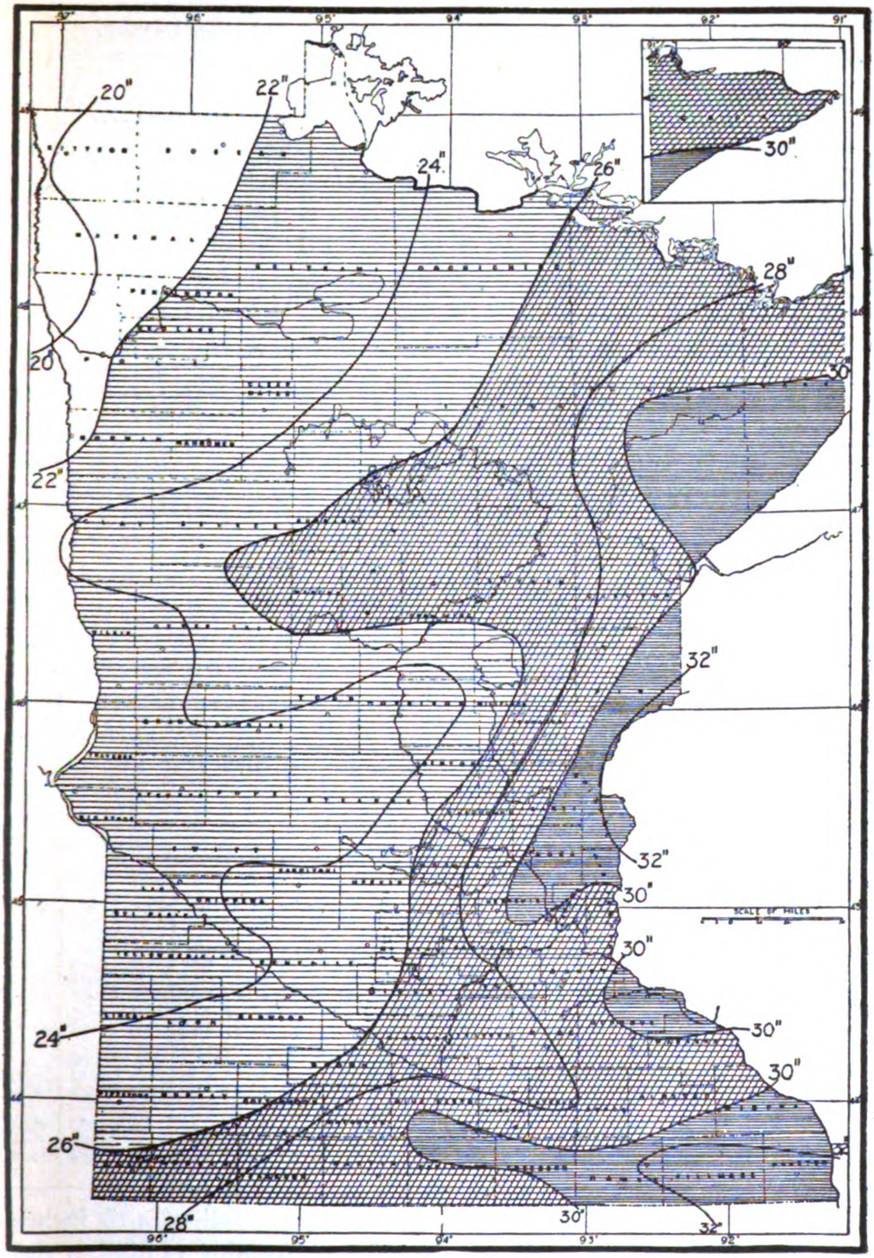


FIGURE 12. MAP SHOWING THE AVERAGE ANNUAL PRECIPITATION FOR MINNESOTA

Table III. Average Monthly and Annual Precipitation for Minnesota (in Inches)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Total April to Sept. incl.
1895	....	....	....	1.68	3.30	4.37	3.25	2.27	3.93	0.25	1.22	0.28	.....	18.80
1896	0.76	0.39	1.97	5.91	5.02	4.07	1.88	2.28	2.49	2.95	2.69	0.61	32.04	21.65
1897	1.77	1.21	2.07	1.55	1.38	5.40	6.62	2.54	1.89	1.55	0.53	0.38	27.23	19.38
1898	0.16	1.02	1.21	1.64	3.26	3.93	2.94	3.22	1.52	3.83	1.02	0.18	24.21	16.51
1899	0.60	0.78	1.58	1.49	4.46	6.36	2.84	5.35	1.47	3.22	0.63	0.95	30.14	21.97
1900	0.48	0.56	1.30	1.47	0.90	1.71	5.48	6.44	6.55	3.85	0.62	0.51	29.79	22.55
1901	0.38	0.40	1.68	1.73	1.41	5.81	3.33	2.21	4.34	1.86	0.78	0.57	24.26	18.83
1902	0.44	0.67	0.92	1.67	5.10	3.32	4.76	4.35	2.23	1.93	1.57	1.79	29.46	21.43
1903	0.45	0.59	1.75	2.82	5.37	1.96	5.11	4.65	5.63	3.13	0.35	0.84	32.85	25.54
1904	0.39	0.62	1.51	1.72	2.43	4.26	3.96	2.77	3.14	3.50	0.14	0.82	29.65	18.28
1905	0.65	0.55	1.21	1.46	5.54	6.41	4.12	4.36	3.45	2.53	2.64	0.15	33.10	25.34
1906	1.15	0.27	1.20	1.72	5.58	4.55	2.93	4.66	3.73	2.28	1.82	0.91	31.66	23.17
1907	1.17	0.58	0.94	1.01	2.14	4.31	3.57	4.11	3.48	1.31	0.57	0.57	24.03	18.62
1908	0.31	1.11	1.47	2.55	6.31	6.35	3.21	2.07	2.41	1.91	1.18	0.79	29.49	22.90
1909	1.32	1.31	0.54	1.89	3.36	3.53	3.84	5.54	3.16	1.56	2.68	1.54	29.27	20.32
1910	0.83	0.45	0.27	1.54	1.58	1.39	1.94	2.35	2.45	0.97	0.52	0.44	14.73	11.25
1911	0.81	0.88	0.63	1.88	3.48	3.79	3.61	4.27	3.35	3.93	1.12	1.35	29.10	20.38
1912	0.40	0.21	0.45	2.04	4.13	1.66	4.30	3.97	3.03	0.97	0.36	0.93	22.45	19.13
1913	0.33	0.44	1.27	1.87	3.53	3.08	5.56	2.79	3.33	2.58	0.66	0.05	25.49	20.16
1914	0.81	0.44	1.12	2.41	2.89	8.34	2.48	3.97	3.08	2.00	0.38	0.44	28.06	23.77
Mean	0.70	0.66	1.22	2.00	3.56	4.18	3.79	3.66	3.23	2.31	1.07	0.71	27.74	20.33

Precipitation.—The annual average precipitation of the state as a whole for a period of nineteen years, 1896 to 1914 inclusive, is 27.74 inches, and for the crop season, April to September inclusive, for twenty years, 1895 to 1914, is 20.33 inches. The monthly, seasonal, and annual averages for this period are shown in Table III. The year with the greatest annual rainfall was 1905, when the total was 33.10 inches. The driest year was 1910 with 14.73 inches. In that year the rainfall during the crop-growing season was 11.25 inches.

Table IV. Average Monthly and Annual Precipitation by Drainage Districts

Watersheds	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Lake Superior..	0.88	0.88	1.41	2.05	3.50	4.19	4.21	3.73	4.18	2.80	1.45	1.13	30.40
Rainy River....	0.94	0.94	1.42	1.96	3.10	4.04	3.76	3.32	2.98	2.08	1.46	0.98	26.98
Red River.....	0.55	0.56	0.98	1.84	2.85	3.83	3.34	3.12	2.32	1.55	0.72	0.56	22.22
Mississippi (above St. Croix)....	0.73	0.70	1.23	2.16	3.42	4.13	3.61	3.57	3.00	2.29	1.05	0.73	26.63
St. Croix and Mississippi (below St. Croix)....	0.92	0.95	1.49	2.37	4.01	4.46	3.72	3.69	3.72	2.73	1.36	1.13	30.57
Minnesota River	0.79	0.73	1.19	2.30	3.52	4.18	3.34	3.44	2.63	2.11	1.02	0.79	26.04
Big Sioux and Des Moines Rivers	0.50	0.54	1.13	2.09	4.00	4.39	3.49	3.58	2.79	2.07	0.94	0.63	26.15
State.......	0.76	0.75	1.25	2.18	3.53	4.19	3.55	3.50	3.02	2.24	1.09	0.84	26.90

June is the wettest month with an average rainfall of 4.18 inches, and July is next with 3.79 inches. The lowest monthly rainfall is that of February with an average of 0.66 inch. The greatest rainfall in one month for the state as a whole was 8.34 inches in June, 1914. The lowest rainfall for any month was .05 inch in December, 1913.

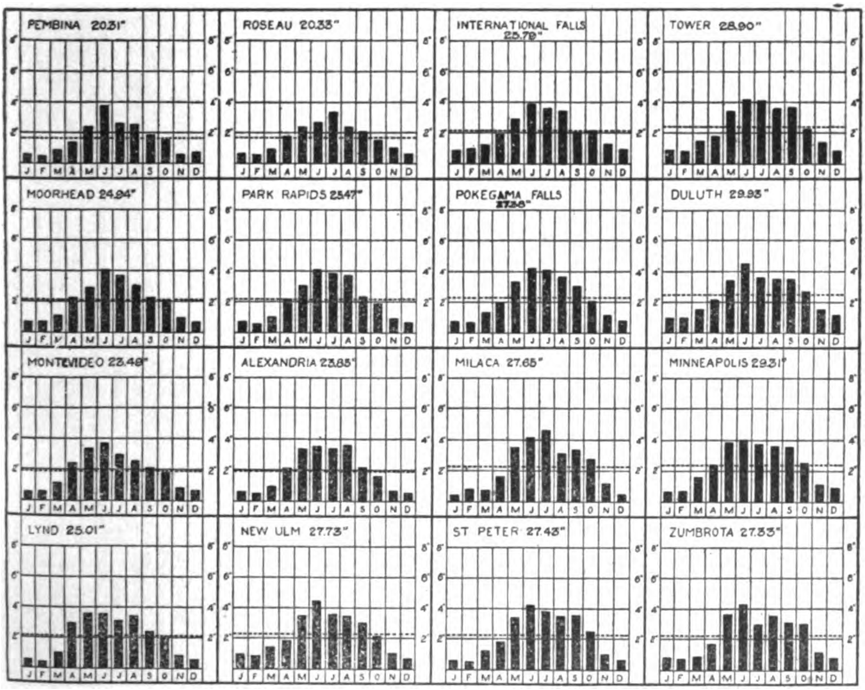


FIGURE 13. DIAGRAM SHOWING COMPARATIVE MONTHLY DISTRIBUTION OF PRECIPITATION IN MINNESOTA. LETTERS INDICATE MONTHS, BLACK COLUMNS INDICATE INCHES OF RAINFALL IN EACH MONTH AT STATION NAMED

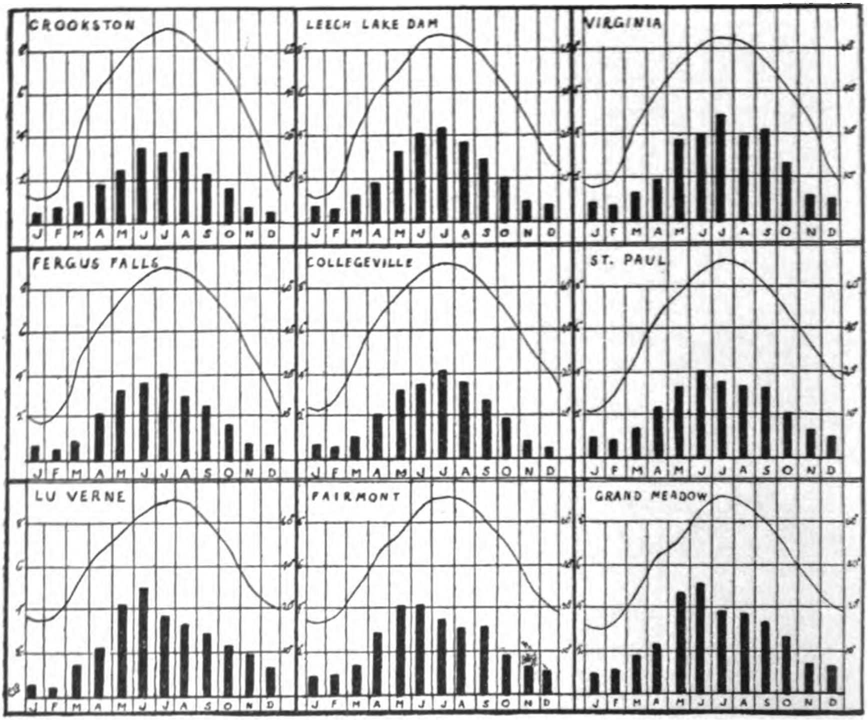
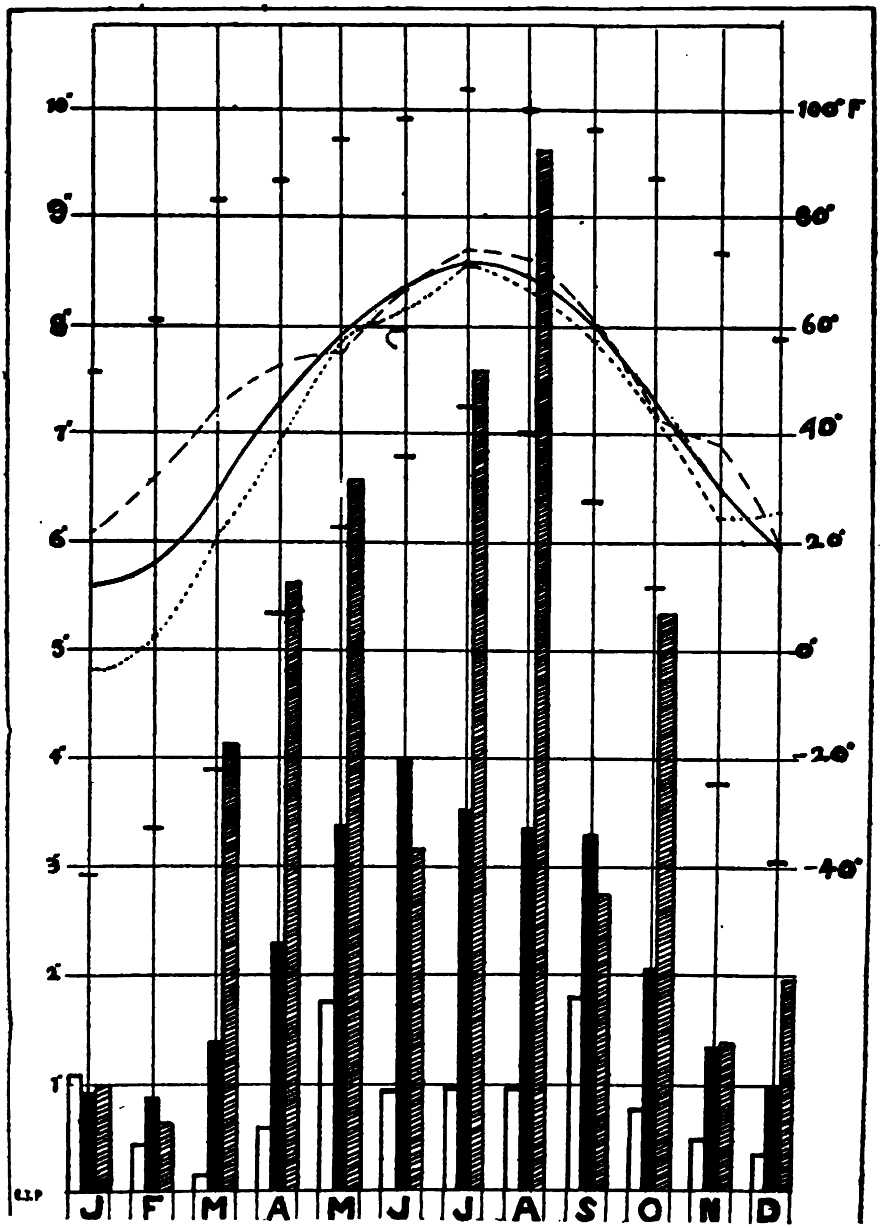


FIGURE 14. DIAGRAM SHOWING MEAN MONTHLY RAINFALL AND MEAN MONTHLY TEMPERATURE AT SEVERAL STATIONS IN MINNESOTA. MONTHS ARE INDICATED BY THEIR FIRST LETTERS. THE GREATEST RAINFALL IS IN THE GROWING SEASON



■ =mean monthly rainfall, 1873-1913.
▨ =monthly rainfall of year of greatest rainfall recorded, 1849.
☐ =monthly rainfall of year of least rainfall recorded, 1910.
Solid curve=mean monthly temperature, 1871-1913.
Dotted curve=mean monthly temperature for year of lowest annual temperature recorded, 1875.
Dashed curve=mean monthly temperature for year of highest annual temperature recorded, 1878.
Horizontal dashes show absolute maximum and minimum temperatures recorded.

FIGURE 15. DIAGRAM SHOWING RAINFALL AND TEMPERATURES (DEGREES FAHRENHEIT) AT ST. PAUL, MINNESOTA FROM 1837-1913. MONTHS ARE INDICATED BY THEIR FIRST LETTERS

The geographic distribution of annual and monthly precipitation is graphically shown in Figures 12 to 14, and for the stations having ten or more years of record in Table V. Table IV shows the monthly and annual distribution in the various watersheds. From these illustrations it may be seen that the precipitation is about one-fourth to one-third greater along the eastern boundary of the state than along the western boundary.

Table V. Average Annual Precipitation in Minnesota by Stations

Stations	County	Length of record	Average annual precip.	Station	County	Length of record	Average annual precip.
		Yrs.	Inches			Yrs.	Inches
Albert Lea	Freeborn ..	21	29.90	Montevideo	Chippewa ..	22	23.50
Alexandria	Douglas ...	25	23.74	Moorhead	Clay	31	24.92
Angus	Polk	10	19.00	Morris	Stevens ...	27	23.23
Ashby	Grant	14	24.47	New London	Kandiyohi..	18	23.62
Beardsley	Bigstone ...	16	23.79	New Richland	Waseca	10	29.91
Bird Island........	Renville ...	22	24.23	New Ulm	Brown	32	27.74
Blooming Prairie...	Steele	13	27.45	Northfield	Rice	12	29.92
Caledonia	Houston ...	19	33.70	Osceola, Wis.	Polk	21	32.13
Collegeville	Stearns ...	19	22.76	Park Rapids	Hubbard ...	22	25.71
Crookston	Polk	22	22.41	Pembina, N. D.....	Pembina ..	14	19.79
Detroit	Becker	16	25.96	Pine River Dam...	Crow Wing.	25	27.52
Duluth	St. Louis...	41	29.93	Pipestone	Pipestone ..	12	24.18
Fairmont (near) ..	Martin	25	28.20	Pokegama Falls....	Itasca	25	27.62
Faribault	Rice	14	28.00	Red Wing	Goodhue ..	16	31.71
Farmington	Dakota	24	29.29	Redwood Falls	Redwood ..	13	24.65
Fergus Falls	Otter Tail..	24	23.24	Reeds Landing ...	Wabasha ..	16	29.31
Flandreau, S. D....	Moody	22	24.57	St. Charles	Winona ...	21	30.68
Fort Ripley........	Crow Wing.	43	25.25	St. Cloud	Sherburne .	19	27.68
Glencoe	McLeod ...	15	26.64	St. Paul...........	Ramsey ...	41	28.68
Grand Meadow ...	Mower	24	32.59	St. Peter..........	Nicollet ...	18	27.89
Grantsburg, Wis....	Burnett ...	21	33.06	Sandy Lake Dam...	Aitkin	19	26.47
Hallock	Kittson ...	13	21.37	Shakopee	Scott	15	28.85
Halstad (Ada)	Norman ...	16	21.27	Tonka	Hennepin...	13	30.54
International Falls.	Koochiching.	10	25.75	Tower (Ely)	St. Louis...	10	28.17
La Crosse, Wis....	La Crosse .	40	31.17	Two Harbors......	Lake	18	30.56
Leech Lake Dam..	Cass	24	27.00	University, N. D...	Grand Forks	20	20.47
Long Prairie	Todd	20	25.17	Virginia (Mt. Iron)	St. Louis...	18	30.74
Luverne	Rock	15	27.60	Wabasha	Wabasha ..	17	30.54
Lynd	Lyon	19	25.43	Wahpeton, N. D...	Richland ..	20	23.67
Mankato	Blue Earth.	14	27.50	Willmar	Kandiyohi..	10	25.54
Mapleplain	Hennepin .	17	31.11	Willow River	Pine	10	29.98
Milaca	Mille Lacs.	13	27.27	Winnebago	Faribault ..	14	30.58
Milan	Chippewa ..	18	24.49	Winnibigoshish	Itasca	25	25.66
Milbank, S. D.....	Grant	21	22.69	Winona	Winona ...	16	29.63
Minneapolis	Hennepin ..	21	29.31	Worthington	Nobles	17	28.24

Figure 14 makes an interesting comparison of monthly and annual values of both temperature and rainfall at certain selected representative stations.

Snowfall.—The snowfall averages from 24 to 54 inches. It is lightest in the southwest portion of the state and heaviest on the Mesabi Iron Range. The monthly and annual averages are shown in Table VI, arranged according to sections and drainage districts.

Winds.—The prevailing winds are from the northwest over most of the state. The monthly and annual prevailing directions are shown for a large group of stations in Table VII. The average hourly wind velocity is shown for six regular Weather Bureau stations and three special stations in Table VIII.

Table VI. Average Snowfall

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
	Yrs.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Lake of the Woods Group—														
Tower	9	9.0	8.6	10.9	4.2	0.6	0	0	0	0.2	0.4	8.4	8.2	50.5
Red River Valley Group—														
St. Vincent-Pembina	14	8.4	5.1	6.9	5.2	0.7	0	0	0	0.1	0.7	5.7	6.4	39.2
Crookston	14	6.3	6.7	8.8	3.2	2.0	0	0	0	T.	0.4	4.5	5.7	35.8
Moorhead	17	7.6	6.7	8.9	4.9	0.3	0	0	0	0.1	1.0	6.9	6.8	43.7
Upper Mississippi River Valley Group—														
Park Rapids	14	9.0	6.5	9.1	5.4	0.9	0	0	0	0.2	1.4	7.4	6.3	46.2
Lake Winnibigoshish	14	8.6	6.5	9.9	3.3	0.8	0	0	0	T.	1.0	7.8	7.8	45.7
Sandy Lake Dam	14	9.0	9.5	10.6	3.6	0.7	0	0	0	0.2	1.1	7.4	7.4	49.4
Lake Superior Group—														
Mt. Iron	13	9.9	7.8	11.2	3.9	1.1	0	0	0	0.1	0.8	8.1	11.6	54.4
Duluth	25	10.3	9.1	11.1	4.0	1.0	0	0	0	0.1	0.3	8.2	8.7	52.8
Lower Mississippi River Valley Group—														
La Crosse, Wis.	15	8.4	8.7	6.6	1.4	T.	0	0	0	T.	0.1	3.9	8.9	37.1
Grand Meadow	14	8.0	9.8	9.9	3.1	0.4	0	0	0	T.	0.3	5.3	9.3	46.1
St. Charles	9	7.7	9.4	9.5	2.4	0.2	0	0	0	0	0.1	4.3	9.3	42.9
Red Wing	8	8.0	5.6	4.4	1.8	0.2	0	0	0	T.	0.3	1.5	7.1	28.9
St. Paul	24	7.7	6.2	8.8	3.6	0.2	0	0	0	T.	0.2	4.7	5.7	37.1
Lower Minnesota River Valley Group—														
Shakopee	14	7.7	8.1	7.8	1.9	T.	0	0	0	T.	0.4	3.0	4.6	33.5
St. Peter	13	5.5	6.1	7.1	0.7	T.	0	0	0	0	0.4	1.4	4.0	25.2
Winnebago	10	6.5	7.5	6.3	1.0	T	0	0	0	T.	0.3	2.3	6.5	30.4
Middle Mississippi River and St. Croix Valleys Group—														
Minneapolis	18	8.3	8.6	9.5	4.0	0.2	0	0	0	T.	0.3	4.5	6.4	42.4
Collegeville	14	6.7	5.6	8.5	1.8	0.4	0	0	0	T.	0.3	3.5	5.0	31.8
Pine River Dam	14	9.1	8.4	9.5	2.8	2.8	0	0	0	0.1	0.6	5.9	6.8	44.0
Osceola, Wis	11	9.1	8.4	11.7	2.8	T.	0	0	0	T.	0.1	5.5	6.8	44.4
Grantsburg, Wis.	11	9.2	9.0	12.2	4.2	0.1	0	0	0	0	0.1	8.5	8.9	52.2
Upper Minnesota River Valley Group—														
New Ulm	14	8.9	7.5	9.5	1.7	0.2	0	0	0	T.	0.3	3.5	4.4	36.0
Bird Island	14	4.7	5.8	6.0	1.5	0.4	0	0	0	T.	0.5	3.5	3.4	25.8
Milan	14	7.5	8.1	11.2	1.6	0.5	0	0	0	T.	0.6	4.1	6.1	39.7
Minnesota River Watershed Group—														
New London	14	4.6	4.2	7.0	1.7	0.1	0	0	0	0	0.3	2.7	3.4	24.0
Long Prairie	14	5.7	5.5	7.4	2.4	0.4	0	0	0	T.	0.2	3.3	4.4	29.3
Morris	14	5.2	5.4	7.8	2.1	0.5	0	0	0	0	0.6	3.2	4.4	29.2
Fergus Falls	13	6.2	5.7	7.6	2.8	0.4	0	0	0	T.	1.0	5.7	5.8	35.2
Southwestern Group—														
Fairmont	13	5.0	10.0	8.8	1.9	0.1	0	0	0	T.	0.2	3.9	5.3	35.2
Worthington	13	4.1	7.2	7.6	1.2	T.	0	0	0	0	0.3	2.7	3.6	26.7
Lynd	14	6.3	5.1	7.4	2.8	0.5	0	0	0	T.	1.2	2.8	5.3	31.4
Gary, S. D.	11	4.4	6.6	12.4	4.5	0.2	0	0	0	T.	1.2	4.2	4.1	37.8

Relative humidity.—The average annual humidity for the state is 83 per cent at 7 a.m. and 72 per cent at 7 p.m. Table IX gives the monthly and annual data.

Number of rainy days.—In Table X the number of rainy days during each month and the year is given for thirty-three stations well distributed over the state. The smallest number is 64 at Lynd, Lyon County, and the largest 132 days at Duluth.

Sunshine.—The sunshine is abundant, averaging from 43 to 53 per cent of the highest amount possible. The daylight hours are materially longer during the crop-growing season in the northern portion of the state than in the southern. The greatest percentage of sunshine is in the southwestern portion and the least in the northeastern part.

Table VII. Prevailing Wind Direction

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Year
Lake of the Woods Group—														
Tower	9	nw.	w.	nw.	w.	w.	w.	w.	w.	w.	w.	w.	nw.	w.
Red River Valley Group—														
St. Vincent-Pembina	23	nw.	nw.	nw.	nw.	nw.	se.	s.	se.	nw.	nw.	nw.	nw.	nw.
Crookston	14	s.	nw.	s.	n.	nw.	s.	sw.	se.	nw.	s.	s.	nw.	s.
Moorhead	28	nw.	nw.	nw.	n.	n.	se.	s.	se.	se.	se.	nw.	nw.	n.
Upper Mississippi River Valley Group—														
Park Rapids	16	nw.	nw.	nw.	nw.	s.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
Lake Winnibigoshish	16	nw.	nw.	w.	nw.	nw.	w.	w.	w.	w.	nw.	nw.	nw.	nw.
Sandy Lake Dam	14	nw.	nw.	nw.	se.	e.	e.	nw.	nw.	s.	nw.	nw.	nw.	nw.
Lake Superior Group—														
Mt. Iron	14	nw.	n.	n.	n.	n.	s.	s.	n.	s.	s.	nw.	nw.	n.
Duluth	38	sw.	nw.	ne.	ne.	ne.	ne.	ne.	ne.	ne.	ne.	sw.	sw.	ne.
Lower Mississippi River Valley Group—														
La Crosse, Wis.	36	s.	s.	n.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
Grand Meadow	15	nw.	nw.	nw.	nw.	nw.	se.	s.	s.	s.	sw.	nw.	nw.	nw.
St. Charles	13	nw.	nw.	se.	se.	nw.	se.	se.	nw.	s.	se.	nw.	nw.	nw.
Red Wing	12	nw.	nw.	nw.	se.	e.	se.	sw.	w.	e.	w.	nw.	nw.	nw.
St. Paul	38	nw.	nw.	nw.	nw.	se.	se.	se.	se.	se.	se.	nw.	nw.	se.
Lower Minnesota River Valley Group—														
Shakopee	14	nw.	nw.	nw.	se.	se.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
St. Peter	13	nw.	nw.	nw.	nw.	nw.	nw.	se.	nw.	s.	nw.	nw.	nw.	nw.
Winnebago	9	nw.	nw.	nw.	nw.	se.	se.	se.	se.	se.	se.	nw.	nw.	nw.
Middle Mississippi River and St. Croix Valleys Group—														
Minneapolis	18	nw.	nw.	nw.	nw.	ne.	s.	s.	s.	s.	s.	nw.	nw.	nw.
Collegeville	14	nw.	nw.	nw.	s.	nw.	sw.	s.	nw.	s.	nw.	nw.	nw.	nw.
Pine River Dam	16	nw.	nw.	nw.	nw.	nw.	w.	w.	nw.	nw.	nw.	nw.	nw.	nw.
Osceola, Wis.	11	s.	s.	n.	n.	s.	s.	s.	s.	s.	n.	n.	s.	s.
Grantsburg, Wis.	11	nw.	nw.	sw.	se.	ne.	sw.	sw.	sw.	sw.	nw.	nw.	nw.	nw.
Upper Minnesota River Valley Group—														
New Ulm	14	nw.	nw.	s.	s.	s.	s.	s.	s.	nw.	nw.	nw.	nw.	nw.
Bird Island	16	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
Milan	14	nw.	nw.	nw.	se.	se.	se.	nw.	se.	nw.	nw.	nw.	nw.	nw.
Minnesota River Watershed Group—														
New London	14	nw.	nw.	nw.	se.	se.	se.	se.	se.	se.	se.	nw.	nw.	se.
Long Prairie	14	nw.	nw.	nw.	se.	se.	nw.	nw.	se.	se.	nw.	nw.	nw.	nw.
Morris	17	nw.	nw.	s.	s.	s.	s.	s.	s.	s.	s.	n.	s.	s.
Fergus Falls	13	nw.	nw.	nw.	se.	se.	se.	nw.	se.	nw.	nw.	nw.	nw.	nw.
Southwestern Group—														
Fairmont	15	nw.	nw.	nw.	nw.	nw.	s.	s.	nw.	s.	nw.	nw.	nw.	nw.
Worthington	13	nw.	nw.	nw.	s.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
Lynd	14	nw.	nw.	nw.	nw.	se.	nw.	sw.	nw.	nw.	sw.	nw.	nw.	nw.
Gary, S. D.	11	nw.	nw.	nw.	sw.	se.	se.	se.	s.	ne.	sw.	nw.	nw.	nw.

Table VIII. Average Hourly Wind Velocity in Miles

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Duluth	5	14.3	14.2	15.0	15.1	15.2	11.6	11.3	12.0	12.7	13.9	14.1	14.2	13.6
Moorhead	19	10.3	10.5	11.3	12.0	10.7	10.0	8.3	8.4	10.4	10.4	10.1	10.0	10.2
St. Vinc'nt-Pembina	15	7.7	9.4	10.0	10.7	10.9	8.7	7.5	7.5	9.1	9.3	9.5	8.9	9.2
Two Harbors	6	9.0	8.2	9.7	9.4	7.6	7.4	7.3	7.2	8.0	8.3	8.7	8.9	8.3
La Crosse, Wis.	36	7.1	7.5	8.0	8.5	7.5	6.7	6.0	5.8	6.9	7.5	7.5	7.2	7.2
St. Paul	36	7.8	8.3	8.8	9.3	8.7	7.7	7.1	7.1	8.0	8.5	8.1	7.8	8.1
Minneapolis	18	11.5	11.6	12.3	12.8	12.1	10.3	9.9	9.9	11.6	11.7	11.0	11.2	11.3
Faribault	7	9.4	9.1	9.4	11.0	9.0	7.3	5.9	6.4	7.8	8.8	9.0	9.1	8.5
Collegeville	11	9.5	9.6	11.0	12.2	11.1	10.0	9.4	9.4	10.9	9.5	9.9	9.9	10.2

Table IX. Mean Relative Humidity in Degrees

Stations		Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Duluth..........	8 a.m.	21	83	83	81	76	76	79	79	81	82	81	83	84	81
	8 p.m.	21	77	75	71	65	64	69	65	69	71	72	76	78	71
Moorhead	8 a.m.	21	89	88	88	84	79	84	86	87	87	84	89	89	86
	8 p.m.	21	86	86	82	65	56	62	64	61	63	69	81	85	72
St. Vincent.....	8 a.m.	4	80	80	88	88	79	84	88	90	87	89	89	87	86
	8 p.m.	4	83	86	88	77	58	66	71	70	71	78	89	89	77
La Crosse, Wis..	.8 a.m.	21	83	82	79	74	75	79	81	85	85	81	81	83	81
St. Paul.......	8 a.m.	21	84	84	81	75	75	79	79	83	83	81	81	83	81
	8 p.m.	21	76	75	68	55	54	58	55	56	60	63	69	76	64
Minneapolis......	8 p.m.	7	83	79	76	66	66	67	65	68	72	73	79	83	74

Table X. Number of Days with 0.01 Inch or More of Precipitation

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Lake of the Woods Group—														
Tower	9	5	4	6	5	8	9	10	8	10	7	5	5	82
Red River Valley Group—														
St. Vincent-Pembina...	25	7	6	7	7	8	11	10	9	8	7	7	7	94
Crookston	14	4	4	5	6	8	10	8	8	6	5	3	4	71
Moorhead	28	8	9	8	9	11	12	10	9	8	8	7	8	107
Upper Mississippi River Valley Group—														
Park Rapids..........	14	8	7	10	9	11	13	11	10	9	9	7	8	112
Lake Winnibigoshish...	15	6	4	7	6	10	10	9	8	7	5	5	6	83
Sandy Lake Dam.....	14	6	6	8	6	10	10	10	10	9	8	6	6	95
Lake Superior Group—														
Mt. Iron............	14	5	4	5	5	9	11	10	9	9	7	5	6	85
Duluth	38	10	9	10	9	12	14	12	12	12	10	11	11	132
Lower Mississippi River Valley Group—														
La Crosse, Wis.......	36	10	8	10	10	12	12	10	9	10	9	8	10	120
Grand Meadow........	15	6	5	7	7	12	9	9	8	8	7	6	6	90
St. Charles..........	12	5	4	6	6	9	11	7	6	8	7	5	4	78
Red Wing............	10	5	5	6	7	11	10	7	7	8	6	5	5	82
St. Paul.............	38	9	8	10	10	12	12	10	10	9	9	8	9	114
Lower Minnesota River Valley Group—														
Shakopee	14	5	5	7	8	11	10	9	9	9	8	6	5	92
St. Peter............	12	3	3	5	6	10	9	7	7	6	5	3	2	66
Winnebago	10	4	4	6	6	12	11	9	9	7	7	3	4	82
Middle Mississippi River and St. Croix Valleys Group—														
Minneapolis	18	8	7	9	9	12	12	9	9	8	9	7	8	107
Collegeville	14	6	5	8	7	10	12	10	10	9	8	6	5	96
Pine River Dam......	15	4	4	6	6	9	10	8	8	7	6	4	4	76
Osceola, Wis..........	11	7	5	6	6	8	9	8	7	6	7	5	5	79
Grantsburg, Wis.......	11	5	4	5	6	8	7	7	6	5	4	5	6	68
Upper Minnesota River Valley Group—														
New Ulm.............	14	5	5	7	7	11	11	8	8	8	7	5	4	86
Bird Island...........	14	4	3	6	7	10	10	8	8	8	6	5	3	78
Milan	14	6	5	7	7	9	11	8	8	7	6	5	5	84
Minnesota River Watershed Group—														
New London..........	14	3	3	5	5	9	9	7	6	6	5	4	3	65
Long Prairie..........	14	4	4	6	8	10	11	8	8	8	7	5	3	82
Morris	16	4	4	6	7	11	12	9	9	7	6	4	4	83
Fergus Falls..........	13	11	8	11	9	12	15	11	11	10	8	7	10	123
Southwestern Group—														
Fairmont	15	4	4	5	6	10	8	7	7	7	5	3	3	69
Worthington	13	4	4	4	6	11	10	14	8	6	5	4	4	80
Lynd	14	3	3	5	5	8	9	7	8	6	4	3	3	64
Gary, S. D...........	11	3	2	3	5	6	5	6	5	4	4	3	1	47

The precipitation in the area embraced in the present report, as shown in Figure 12, increases from northwest to southeast, being about 25 inches in the northwest part and over 32 inches in the southeast. Although there is an increase on approaching Lake Superior the influence of the lake in increasing precipitation near its shore seems to be very slight, for in parts of Minnesota farther south where there is no lake influence a similar increase in the amount of precipitation is found in passing from northwest to southeast.

CHAPTER III

AGRICULTURAL CONDITIONS AND LAND CLASSIFICATION IN THE SOUTH HALF OF MINNESOTA

GENERAL STATEMENT

The area embraced in this report extends from the median line of the state, about latitude 46° 25′, southward to the Iowa state line. It embraces about 40,000 square miles, including lakes. It is largely tributary to the Mississippi River, there being only about 3,550 square miles, or less than 9 per cent drained by other streams. Of this, 60 to 70 square miles in the northeast corner of Pine County drains northeastward to Lake Superior; about 1,840 square miles is tributary to Red River of the North; and 1,650 square miles is drained southwestward to the Missouri River. In the Mississippi drainage about 15,000 square miles falls within the Minnesota River watershed, and over 21,000 square miles in the main stream and other tributaries of the Mississippi. Part of this is drained by the Des Moines, Cedar, and upper Iowa rivers across Iowa to the Mississippi, while the St. Croix River flows along the border of the state to its junction with the Mississippi.

The altitude of the south half of the state has a range of about 1,350 feet, the lowest being 615 feet, at the southeast corner of the state, and the highest 1,950 to 1,975 feet, in high points on the Coteau des Prairies in the southwest part. The average altitude is not far from 1,200 feet. Only a small part aside from river valleys is below 1,000 feet, and only a small part above 1,500 feet.

The average rainfall ranges from less than 24 inches, in the western part, to 30 to 32 inches in the eastern (Figure 12). The rainfall is largely in the crop-growing season, and is usually sufficient for the proper maturing of all the crops.

As indicated in the discussion of the general features of the state, the topographic and agricultural conditions are quite varied. It may, therefore, be of advantage to outline briefly certain of the characteristics of each of the several classes of land, beginning with the driftless area, and taking up the several drifts and associated deposits in order of their age and the alluvial deposits of the present streams.

DRIFTLESS AREA

The portion of Minnesota falling within the driftless area of the upper Mississippi valley is confined to Houston County and the eastern part of Winona County. In this area the uplands have a residuary clay covering the rock to a depth of a few feet, above which there is a deposit of wind borne silt-loam (loess) having a depth of 10 to 15 feet or more. This loess extends down on the gentle slopes from the crests of the divides between the streams, leaving only the steeper part of the slopes with rock exposed. This area is, therefore, rendered more productive by the presence of the deposit of loess which has buried the less productive residuary clays beneath it. The steep parts of the slopes which are difficult to till are utilized to a large degree for pasture.

LOESS-COVERED PRE-WISCONSIN GRAY DRIFT

Pebbly border.—For several miles back from the eastern limits of the old drift there are usually only scattered pebbles and occasional bowlders to mark the former extent of glaciation. The topography is indistinguishable from that of the driftless area, and the glaciation was usually so weak that the preglacial residuary clay is still present on the rock formation. A sheet of loess covers the pebbles to a depth of 10 to 15 feet or more, and it is this which gives the productiveness to the soil. A considerable part of Wabasha County, western Winona County, eastern Olmsted County, eastern Fillmore County, and western Houston County falls within the limits of this pebble and bowlder area. Rock bluffs are about as conspicuous as in the driftless area, but the valleys of tributaries of the Mississippi are narrower than on the lower courses of the streams in the driftless area proper.

Old gray till (Kansan).—The loess overlaps for a few miles the eastern edge of heavy deposits of an old calcareous till. This was leached to a depth of several feet before the deposition of the loess, and is usually oxidized to a yellowish brown color to a depth of 15 to 20 feet. When of greater thickness, it retains the original bluish gray color. Eastern Goodhue County, southwestern Wabasha County, western Olmsted County, northeastern Dodge County, and part of the western half of Fillmore County, have thick deposits of old drift beneath the loess. The loess, however, is so heavy a deposit as a rule that the crops are dependent upon it rather than upon the underlying drift. The amount of this drift is sufficient to reduce greatly the roughness of the surface.

There is an area of the old gray drift in the southwest corner of the state in Rock, Pipestone, and Nobles counties, of which about 170 square miles in the extreme southwest corner of the state, were covered by a deposit of loess to several feet in depth, or of sufficient thickness to entirely sustain the crops. This gives place on the north and east somewhat abruptly to a thin coating of wind drifted silt a few inches to 2 or 3 feet in depth which is not included in the area mapped as loess on the map of the surface formations of Minnesota. Much of the deposit is probably derived from the loess, but the silt is mixed to some extent with sand grains and small pebbles from the underlying till. It appears to have been deposited by winds that were dragging the surface and transporting coarse and fine grains gathered from bare or exposed surfaces of loess or till, a process still in operation. The typical loess, on the other hand, is a very uniform deposit, such as might result from the settling of dust which had been held in the atmosphere. It is not always feasible to draw a definite line or boundary between the deposits, but the map sets forth the approximate extent of the typical loess.

The drift is sufficient in southwest Minnesota to fill the preglacial valleys, but some of the more prominent quartzite ridges stand above the general level of this drift filling. Parts of these ridges are entirely bare, but they seem likely to have formerly carried a coating of drift which has been removed by erosion, for the glaciated surfaces of the rocks frequently have the striae well preserved. This could hardly be the case if they had been exposed to weathering ever since the ice disappeared from this region. The depth of leaching in this old drift is much less than in southeastern Minnesota, being usually but 2 to 3 feet or even less. The difference seems attributable in part at least to the smaller rainfall and a lesser amount of downward penetration of water in southwestern Minnesota.

OLD GRAY DRIFT (KANSAN), WITH LITTLE OR NO LOESS COVER

Immediately west of the loess covered area in southeastern Minnesota is an old gray drift with little or no silt cover over it, which extends westward and passes under the young or Wisconsin gray drift of southern Minnesota. From the state line northward across Mower, Dodge, western Goodhue, eastern Rice, and southwestern Dakota counties, it is very largely composed of clayey till which has been leached of its lime to a depth of several feet, and oxidized to a depth of about 15 feet, below which it retains the original bluish gray color. It has been termed in the earlier reports of the Minnesota Geological Survey the old gray drift. A large part of it appears to be of Kansan age, and its surface was greatly eroded subsequent to the Kansan glaciation.

IOWAN DRIFT OVER KANSAN DRIFT

The southeast part of Minnesota and the northeast part of Iowa include an area which differs somewhat from Kansan drift areas farther south. The general depth of leaching is less than in those areas, and the surface of the drift is not so deeply reddened by oxidation. The valleys in this area are in some cases mere swales without definite bluffs, and as a rule they are shallower than in the Kansan drift areas to the south. There are knolls on the slopes and on the valley bottoms, which in some cases seem to have been deposited in the form of knolls rather than developed by erosion of material around them. In a few places in northeastern Iowa an old soil, which is thought by some geologists to be at the top of the Kansan drift, has over it a thin drift deposit, usually 5 to 10 feet or less in depth.

These features have led certain geologists to think that a readvance of ice into this region took place at a time between the Kansan and Wisconsin stages of glaciation. Opinion is divided as to whether this readvance took place at the Illinoian stage of glaciation or at some later time more nearly contemporaneous with the main loess deposition. Pending the solution of this matter, and the full determination of the significance of the peculiar features just mentioned, a special name, Iowan, has been applied to it. Because of the vagueness of the features the limits of the Iowan drift, or the extent of Iowan glaciation, are matters on which there is wide difference of opinion.

So far as the Minnesota area has been affected by such a post-Kansan glaciation, the effect on crop conditions is likely to be slight. There has been, perhaps, a slight removal of the leached and-weathered surface of the Kansan drift in exposed situations, and redeposition of this material in the valleys and depressions. The valleys of this problematical area often head in shallow draws or sloughs which are wet and ill-drained, but the district is entirely free from lakes and inclosed basins such as abound in the later or Wisconsin drift region. Aside from the sloughs just mentioned the drainage is naturally good.

OLD RED DRIFT (ILLINOIAN), OVER OLD GRAY DRIFT (KANSAN)

In central and eastern Dakota County, northern Goodhue County, and southeastern Washington County, the Kansan or old gray drift has been covered by drift of a somewhat different constitution and color, made up largely of the classes of rock found in the red drift of western Wisconsin and like that apparently deposited by ice from the north or northeast. The clayey portions usually have a red color which is strikingly in contrast with the yellowish brown color of the underlying Kansan drift. It is markedly more weathered than the red drift of Wisconsin age but corresponds in degree of weathering to the Illinoian drift.

This old red drift is generally very stony and it seldom assumes a clayey constitution. It is usually but a few feet in depth, and scarcely makes a continuous cover over the Kansan drift. It includes, however, a prominent range of gravelly hills in southern Dakota County which extends from near Hampton southeastward for several miles in a strip about 2 miles in width. This line of hills has the appearance of a terminal moraine, and there is a somewhat knolly surface eastward from it into northern Goodhue County and northward to Etter, which may mark the continuation of an ice border.

This old red drift is an extensive outlying deposit in western Wisconsin, but its exposure in Minnesota seems confined to the parts of the three counties above named.

YOUNG OR WISCONSIN RED DRIFT (PATRICIAN ICE SHEET)

The young Patrician red drift of the eastern part of this area has been so overridden by later deposits from the Superior lobe of the Labrador ice field, and those of the Keewatin ice field, that it is exposed only in detached areas. One of these areas occupies much of Washington and Ramsey counties and the northern part of Dakota County. It comprises moraines of considerable strength having a stony clayey till, the soil being a stony loam. Associated with the moraines are small outwash plains of gravel and sand in the district north of the Mississippi River, and more extensive outwash plains along and south of the Mississippi River, a considerable part of central and northeastern Dakota County being occupied by these plains.

This strong system of moraines is traceable westward beneath the young gray drift across northern Scott County and the district north of the Minnesota valley in Carver, Hennepin, and Wright counties to where it emerges in Stearns County on the north side of the Grantsburg lobe of the young gray drift. It runs thence northward across central Stearns and eastern Todd counties, and thence northeastward across northwestern Morrison County into Cass County, where it passes beyond the limits of the area here discussed. It has been encroached upon slightly in Stearns and Todd counties by the later advance of the Keewatin ice field, but a large portion of it is still exposed to view. It is generally composed of a very stony clay with stony loam soil.

To the east of this morainic system, occupying much of Morrison, Benton, Mille Lacs, Kanabec, and Pine counties, there is a relatively smooth district of the red Patrician drift, largely till plain, but traversed by a few narrow morainic ridges and including also a few gravel ridges or eskers. The till is a stony clay and often is thickly strewn with bowlders. The clay, however, is of sufficient amount to give a heavier soil than that in the moraines. This is likely to become an important grass growing area and dairy district. A large part of it is as yet very poorly developed, for it was occupied by a mixed coniferous and hardwood forest which was difficult to clear.

Another strong morainic system of the red Patrician drift sweeps around the west and south sides of Mille Lacs Lake and runs eastward across southern Aitkin and northwestern Pine counties, and there passes beneath the drift of the Superior lobe a few miles south of the north limits of the area under discussion. This morainic system has a width of 4 to 8 miles and is composed largely of stony clayey till with stony loam soil. Outwash plains of gravel and sand border it on the west in Crow Wing County and are included among its ridges in northwestern Pine County.

North and east of Mille Lacs Lake is a till plain of red Patrician drift extending eastward and passing beneath the moraines of the Superior lobe in the southern part of Aitkin County. As yet this till plain is very thinly settled, but its soil is suitable for pasture and meadows, like that of the till plain to the south of the moraine which borders the west and south sides of Mille Lacs Lake.

In the till plain in Morrison, Benton, and Mille Lacs counties the young red drift is so thin that the courses of the interglacial valleys are still traceable. These valleys were cut in the old gray drift which underlies that part of Minnesota at least as far east as Mille Lacs Lake.

YOUNG OR WISCONSIN RED DRIFT (LABRADORIAN ICE SHEET)

The Superior ice lobe of the Labrador field extended but a few miles south of the median line of the state in northern Pine and southern Aitkin counties. Its border runs east to west across the northern part of Pine County, and its moraines cross the moraines of the red Patrician drift at a slight angle, the course of the Patrician moraines being there southwestward. There are extensive swampy areas at the terminus of the lobe in southern Aitkin County, with occasional knolls scattered through them, and outside of this to the west a sandy plain which seems to be an outwash from the ice lobe. Narrow till plains are inclosed between the constituent ridges of the moraines of the Superior lobe. There are also numerous swamps interrupting the morainic ridges all along their course across Pine County. The moraines are also interrupted by a gravelly plain extending northward from Willow River past Sturgeon Lake which seems to have been a main line of discharge from the Superior ice lobe down Kettle River to the St. Croix and the Mississippi.

The drift of the Superior lobe within this area is largely of clayey till with scarcely as many stones as characterize the Patrician drift. Its soil is, however, a stony loam.

BORDER OF YOUNG GRAY DRIFT (KEEWATIN ICE SHEET) IN CENTRAL MINNESOTA

There is a narrow strip running southward through western Cass, eastern Wadena, and central Todd counties in which the old gray drift is near the surface and has over it a deposit which contains some rocks such as abound in the red drift. The presence of such drift suggests that the Patrician ice may have extended over that area. There are indications also that the Keewatin ice field in later Wisconsin time covered the same area for the greater part, but without making a heavy deposit. The surface material is a mixture of rocks of red drift in gray drift which might have been produced by the incorporating of the pre-Wisconsin gray drift with the Wisconsin red drift of the Patrician ice field. Or it might have been produced by the encroachment of the Keewatin ice on the thin edge of the red drift and incorporation of that drift in the Wisconsin gray drift. That the latter seems to have been the case is inferred from certain peculiarities of topography. The surface presents a peculiarly smooth appearance as far east as the edge of the strong moraine of red drift which runs through eastern Todd County, and the smoothness in places runs up a slope to that moraine. There is no uncertainty of the presence of the Keewatin ice to within a few miles of the west base of the strong red drift moraine, for a definite sheet of young gray drift is found at the surface in the western part of Todd and Wadena counties, and westward from there. The small amount of red drift that is incorporated with the gray in the district west of the prominent red drift moraine has had but little effect upon the character of the soil. It is somewhat more stony than the unmodified gray drift, but has nearly as great fertility as the gray drift ordinarily possesses.

There are narrow morainic ridges of the young gray drift in southwestern Todd and eastern Douglas counties, but a large part of the surface is a relatively smooth plain. In Wadena and eastern Otter Tail counties, there are extensive gravel plains which were largely formed as an outwash from the strong moraines farther west. In western Stearns County a moraine of considerable strength follows down Sauk River, being south of the river from Sauk Center to New Munich and north of the river from there eastward to Cold Spring, beyond which it is merged with later moraines considered below. On either side of this moraine there are till plains with a thin cover of young gray drift. The plain on the northeast extends to the base of the strong moraine of red drift, above discussed, and in places the young gray drift is found veneering the slopes of the red drift moraine; a condition which shows clearly that the Keewatin invasion here culminated after the Patrician ice had begun to recede.

BORDER OF YOUNG GRAY DRIFT IN SOUTHWESTERN MINNESOTA

In southwestern Minnesota, as in central Minnesota, there is a thin sheet of relatively young gray drift, forming a veneer over the eroded surface of the old gray drift, which lies outside the well defined moraines of Wisconsin drift. It covers the southwest corner of Lincoln County and a large part of Pipestone County, the southwest corner of Murray, the northeast corner of Rock, and a considerable area in western Nobles County. It is so thin a deposit that the interglacial valleys cut in the old gray drift are but partially filled and are followed in large part by the modern streams. It contains a mixture of old gray drift with the young gray drift, and masses of the old are often included in this younger deposit, and are easily recognized by the high degree of staining and oxidation as compared with that of the young drift which incloses them. This border district lies outside the limits of a moraine which has been considered by Upham as the limit of the later or Wisconsin drift. It differs from that inside the limits of that moraine in having few undrained basins or depressions. In the latter district the interglacial lines of drainage were more completely filled with the younger drift than in that outside the moraine, so that drainage lines are more generally opened in new courses instead of following the lines of interglacial valleys. In the opinion of the present writers, the drift which veneers the eroded district outside the moraine is not markedly older than that of the moraine which Upham interpreted to be the outer limits of the younger drift, and should, therefore, be included with it.

MORAINES OF SOUTHWESTERN MINNESOTA

A series of strong moraines was formed on the southwest side of the Keewatin ice field in the Wisconsin stage. The outermost of these moraines is the one traced by Upham. It follows the crest of the Coteau des Prairies across Lincoln, Pipestone, Murray, and Nobles counties. It consists of a single ridge as far south as Chandler in Murray County, but from there southward to the state line it has two members separated by a narrow till plain.

Between this moraine and the next younger morainic system there is a narrow till plain in Lincoln County, but it widens out in Murray, Nobles, and Jackson counties and has a width of nearly 30 miles in northeastern Nobles and northwestern Jackson counties. It narrows again on approaching the state line.

The morainic system east of this plain is very strong and complex. Its several constituent morainic ridges are either merged together or closely associated throughout their course in southwestern Minnesota. They traverse western Yellow Medicine, northeastern Lincoln, southwestern Lyon, northeastern Murray, southwestern Cottonwood, and central Jackson counties, and occupy a belt from 8 to 16 miles wide. They all lie along the northeast slope of the Coteau des Prairies, so that the inner ones are at a lower altitude than the outer ones.

These moraines are composed largely of clayey till, but include occasional gravel knolls and the till in places becomes very stony. The plains associated with these moraines have a rich black loam soil.

MORAINES OF SOUTHEASTERN MINNESOTA

From the state line northward to the Minnesota River in a belt embracing much of Freeborn, Steele, Waseca, Rice, eastern Le Sueur, and Scott counties there is a morainic system which was formed on the east side of the Keewatin ice field at the Wisconsin stage of glaciation, and which apparently is the equivalent of the entire series of moraines on the west side just noted. There is also to the east of the outermost strong moraine a narrow strip of Wisconsin drift in which the surface is nearly all plane and the drift thin.

In Scott and Rice and eastern Le Sueur counties the moraines are all bunched together with only narrow strips of till plain among them. But to the southward in Steele and Freeborn counties the till plains between the moraines in places reach a width of several miles.

The moraines are composed largely of clayey till with a pebbly clay loam soil, but gravel knolls are scattered along them, and in places the till is very stony. The till plains have a black clay loam soil of darker color and somewhat less stony drift than the moraines. There are small outwash aprons of sand and gravel associated with the moraines.

OVERLAP OF RED DRIFT BY GRAY DRIFT IN GRANTSBURG LOBE

In the district north of the Minnesota River the Keewatin ice made a great protrusion northeastward over an area that had been lately vacated by the Patrician ice, and deposited a sheet of the young gray drift on the surface of the young red drift. The extent of overlap is in the neighborhood of 75 miles. The end of the lobe is found near Grantsburg, Wisconsin, opposite the southern end of Pine County, Minnesota, but the ice encroached so little on the Wisconsin side of the St. Croix River that glacial drainage appears to have been but slightly interrupted by the extension beyond the river.

A portion of the overlap on the southwest side of the Mississippi River in Wright, Hennepin, and Carver counties shows a veneering of strong red drift moraines by a relatively thin deposit of the gray drift. The gray drift deposit, however, becomes thick enough within a few miles of its border to conceal completely the red drift deposits.

On the northeast side of the Mississippi River the area covered by the Grantsburg lobe has been extensively blanketed by dune sand which covers much of Sherburne, Isanti, and Anoka counties, and extends to the St. Croix River in Chisago County. There are, however, morainic ridges and narrow till plains standing in these areas of dune sand, but most of them are composed largely of stony drift which the Keewatin ice gathered up from the sheet of Patrician drift which it overrode, and incorporated with some of its own more calcareous material. The topographic features also seem due mainly to the Keewatin ice advance. In some cases what had been a gravel plain of red drift has been changed into a ridged or morainic area by a disturbing and heaping up of its deposits, with a veneering mixed with gray till.

The dune sands appear to have lodged generally on the clayey areas of the Keewatin drift and not on the gravel and sand areas. In some cases they are on moraines and in others on till plains. The sand is so fine as to have considerable capillary action, and by thus supplying moisture in dry seasons, has yielded fair returns where cultivated. Bands of fine dust-like deposits in the sand increase its fertility. Situated as it is near the markets of St. Paul and Minneapolis, vegetable growing or market gardening is likely to become a profitable enterprise. It is an important potato growing area.

At the northeast end of the lobe in southern Pine and northern Chisago counties, and also in eastern Chisago County there are till plains associated with narrow morainic ridges, all having a rich pebbly, clay loam soil.

GRAY DRIFT MORAINES OF CENTRAL MINNESOTA

Along the east side of the Keewatin ice field, as already indicated, there was a thin border drift. This is succeeded on the west by a very strong system of moraines which comes into the area under discussion from the north in Otter Tail County, and runs southeastward across Douglas, Pope, northeastern Swift, and central Kandiyohi counties. It branches in eastern Kandiyohi County, and the outer or northern member bears north of east from New London past Paynesville to the chain of lakes north of Eden Valley, and then turns southeastward and runs between Watkins and Kimball into northwestern Wright County, and thence northeastward into the Grantsburg lobe already discussed. The portion north and east of Watkins is at the extreme border of the young gray drift. But farther west it falls short of reaching the red drift border, the interval being filled by the relatively thin border portion of the young gray drift.

The southern or inner member of the great morainic system continues southeastward from central Kandiyohi County to the northwest corner of McLeod County, where it turns abruptly northeastward to form the northwest border of the Grantsburg lobe. By that time the lobe was considerably shrunken, and had its terminus near the Mississippi River.

The moraines of the Grantsburg lobe which correlate with this inner part of the great morainic system curve around in Wright County and run southward across Carver and western Hennepin counties to the Minnesota valley.

This great morainic system is bordered on the east by extensive outwash plains of gravel and sand in Otter Tail, Douglas, Pope, southwestern Stearns, and northern Kandiyohi counties. The drainage was thence down the Mississippi along Sauk River. Farther east there were outwash plains near Kimball which found their drainage eastward to the Mississippi along lines south of Sauk River. Farther east near South Haven and Annandale the outwash plains slope northward to the Mississippi at Clearwater.

From the inner morainic system there was an outwash northward near Litchfield and Darwin into a small lake that occupied the plain bordering North Crow River between Kingston and Manannah, and which discharged northward past Eden Valley and the chain of lakes north of that village to Sauk River valley and thence to the Mississippi. There are also smaller lines of glacial drainage coming into this lake from the west at Manannah. The ice at that time was covering the lower course of Crow River below Kingston, and thus caused the ponding of the waters west of that village. The outwash plains and glacial drainage lines in Meeker County have a fine sandy to gravelly soil, but the old lake bed is covered by a fine lacustrine silt nearly free from pebbles.

This great morainic system is composed of coarse stony drift along much of its eastern border with numerous gravel knolls and ridges included. But as one passes westward or southwestward toward the inner border of the morainic system, a clayey till is found to come in gradually, while gravel knolls and ridges become more and more infrequent. There are occasional small areas of outwash plain in the midst of the morainic system in Otter Tail and Douglas counties, but such features are remarkably rare.

THE GREAT PLAIN OF THE MINNESOTA LOBE

The axis of movement of the Keewatin ice field was along the Minnesota valley from Swift County, near Appleton, to the great bend of the Minnesota at Mankato, and there is found on either side of the river a broad plain rising gradually toward the border of the great morainic systems above discussed. That on the north side of the river covers much of Swift, Chippewa, Kandiyohi, Renville, McLeod, Sibley, and Nicollet counties, while that on the south covers the greater part of Lac qui Parle, Yellow Medicine, Lyon, Redwood, Cottonwood, Brown, Watonwan, Martin, Blue Earth, and Faribault counties.

On this plain a few weak moraines were developed, which mark successive positions of the ice border as it was melting back from the vicinity of Mankato to the headwater part of the Minnesota River. Along the outer border of these moraines are found channels of border drainage which eventually enter the Minnesota, usually along the line of modern streams. They, however, cross from one modern river valley to another because the ice was still covering the lower courses of the more northern and western streams. Thus border drainage which follows the course of Yellow Medicine River will cross over to that of Redwood River and then to Cottonwood, and perhaps to the Watonwan before entering the Minnesota. These channels are better defined on the south than on the north of the Minnesota River, probably because the melting of the ice was more rapid on that side.

In connection with the border drainage there was more or less ponding of the waters along the edge of the ice, so the channels are not continuous from each one of the modern valleys to a neighboring valley in every instance. The effect of this ponding was to cause a deposition of silt over the till, but it seldom reaches a depth of more than a few inches. The ponding was also so short-lived that beaches or definite shore lines seem not to have been developed.

This great plain is largely prairie, and the soil is a rich black loam on its level portions, and a pebbly clay loam on the morainic ridges. These morainic ridges often include gravelly knolls which are of much value in furnishing material for the roads. The portions of the border drainage channels not now utilized by streams are often marshy and ill-drained, but can usually be reclaimed by ditching. The dry portions of the border drainage channels usually have a sandy soil.

Yellow Medicine River is somewhat peculiar in its drainage, in the portion immediately above Hanley Falls. The plain there is so flat that the river has developed a number of channels which branch out and come together again, thus inclosing areas of several square miles in some cases.

The Minnesota valley was broadly and deeply excavated by the outlet of Lake Agassiz. In several places it has branching channels which inclose strips of the upland, sometimes several miles in length and only a mile or two in width, as indicated on the general map (Plate 1). Below Montevideo, however, it has a single broad channel. All along its course there are rock ledges standing up prominently in the bottoms.

THE GREAT RED RIVER PLAIN

Only the eastern part of this plain lies in Minnesota, the western being in the Dakotas. The Red River valley and its southward continuation in the basin drained by the Mustinka and the Bois des Sioux rivers was the axis of movement of the Keewatin ice field. The terminus of the ice lobe was at one time in a moraine which runs along Big Stone Lake and thence eastward across southern Big Stone County into northwestern Swift County, and thence northward along or near the Chippewa River to its source in northeastern Grant County. The ice was thus a broad lobe at its southern end, markedly out of harmony with the last stages of the ice in the Minnesota valley below Big Stone Lake, which had been reduced to a very narrow lobe, as indicated by the moraines each side of the valley. From this it is inferred that the ice made a decided readvance with broader front at the time it reached the position marked by the moraine just outlined. Extensive outwash plains of fine sandy gravel were developed just outside this moraine in southeastern Stevens, western Pope, and northwestern Swift counties, and also in southern Big Stone County.

Between this moraine and the shore of Lake Agassiz there is an extensive till plain covering much of Stevens and Big Stone counties and part of Grant and Otter Tail counties, on which an occasional slight indication of later positions of the ice border are traceable in weak ridges and low hummocks. The ridges are better defined in Grant and Otter Tail counties than farther south. The ice eventually shrank within the limits of the Lake Agassiz area in Traverse, Grant, and Wilkin counties.

THE LAKE AGASSIZ AREA

The portion of the Lake Agassiz area in the southern half of Minnesota lies mainly in Traverse and Wilkin counties, but it touches northwestern Stevens, western Grant, and southwestern Otter Tail counties. The soil is sandy for a few miles at the southern end of this lake area, but elsewhere is a heavier soil. The lake clays are of very slight depth, usually but a few inches, and the till is at the surface over most of the lake bed embraced in the area under discussion. In the northern part of Traverse County, bowlders are exceedingly numerous.

The beaches or shore lines formed at several levels are usually composed of fine gravel suitable for use on roads. They also have been used as lines for highways and for buildings sites.

The soil on the flat areas is a rich black loam, and even the sandy portions have a black sandy loam.

OUTWASH SAND AND GRAVEL PLAINS

There is perhaps no other surface formation in the state that differs so greatly in the character of the soil and in agricultural value as the outwash plains of sand and gravel. In some places these plains have a rich cover of black loam, several inches to several feet in depth, which renders them about as fertile as any land in the state; while at the other extreme they may have a soil or surface of loose sand or gravel subject to drouth and relatively unfertile. Between these extremes the grades of soil range from poor to fair or good. In the present survey the separation and mapping of the extent of each grade of soil in the outwash plains has not been attempted. In the county discussions, however, statements have been inserted which serve to indicate to some extent the local variations in the character of the soil on these plains. But a much more detailed soil survey must be made to bring out properly the agricultural values of each section.

ALLUVIAL BOTTOMS

There are broad alluvial bottoms along the Minnesota River throughout its course from Big Stone Lake to the Mississippi, and along the Mississippi below St. Paul. Those on the Mississippi are subject to overflow at high river stages, and can only be cultivated with profit in the driest years. The lower portion of the Minnesota valley is in process of silting up, for the valley was cut by the outlet of Lake Agassiz to a level 20 to 30 feet below the present level of the stream. The lakes on the border of Scott and Hennepin counties are unfilled parts of this deep channel. The Minnesota valley has stretches of very slight fall immediately above the rock rapids which occasionally appear along its course. In such places the river may be expanded into a lake, as is the case at Lac qui Parle and in Marsh Lake.

The tributaries of the Mississippi River in southeastern Minnesota usually have broad alluvial flats extending some distance up from their mouths, but these are seldom subject to overflow and are in large part under cultivation.

The portion of the Mississippi above Minneapolis has a broad valley formed as a line of glacial drainage, whose bed is a light sandy soil. The stream in postglacial time has cut a small trench in this broad valley. St. Croix River has broad bottom lands in southern Pine and northern Chisago counties, but below high banks border the stream somewhat closely except at Lakeland where there are broad terraces with sandy soil. The lower course of the river, however, below Stillwater is expanded into a lake, known as Lake St. Croix.

FARMING DEVELOPMENT IN MINNESOTA

The census of 1850 gives Minnesota only 5,035 acres, or about 8 square miles of improved land. This was in 157 farms, or an average of 32 acres per farm. In 1860 there were 556,250 acres, or about 870

A. BED OF LAKE AGASSIZ NEAR WHEATON

B. GRAIN FIELD IN BED OF LAKE AGASSIZ NEAR WHEATON

C. GRAY DRIFT TILL PLAIN IN CHISAGO COUNTY

UNIV. OF MICH.

square miles of improved land. There were 18,181 farms with an average of about 31 acres of improved land. There were only 2,924 farms, or 16 per cent, with more than 50 acres of improved land. It thus appears that farming was still in its beginnings as late as 1860.

The farms down to that time were very largely along the river bottoms and in the oak openings in the southeast part of the state. Such forests are easily cleared, and the stumps soon decay; so the pioneers expended only a moderate amount of time and labor in changing these oak openings into agricultural land. This land, too, was naturally well drained, much of it being covered with loess which is a readily pervious silt which would absorb the rainfall rapidly. It also holds moisture and yields it to the crops through capillary action in the dry seasons. The settlements were confined to a narrow belt along the rivers within about a day's haul by team, and the navigable waters of the Mississippi, the St. Croix, and the Minnesota furnished avenues of shipment to the markets. The yield of wheat on the fertile loess soil was high, and this soon became the staple crop. In an early day flour mills were erected along many of the tributaries of the Mississippi, which utilized the water power afforded by these streams. So long as wheat raising was highly profitable, there was very little stock raising. The long cold winters probably also tended to check the stock raising, but by 1870 the wheat yield in the southeastern counties had begun to fall off, and this led to more diversified farming. The seasons in the early 1860's were very favorable for wheat raising, and the yield in the years from 1860 to 1865 averaged about 22 bushels per acre, or 4½ bushels above the average for the state in 1910.

Down to 1870 the settlement was almost entirely in the forested areas of the eastern part of the state. The settlements were very slowly extended into the prairies, not only on account of their remoteness from navigable waters, but also because of lack of fuel and the bleakness of the region and lack of windbreaks. There seems also to have been a feeling of uncertainty as to the productiveness of the prairie land, it being inferred that the lack of timber was due to some deficiency in the soil.

Between 1860 and 1870, notwithstanding the repressing influence of the Civil War, there was a great extension of agriculture over the greater part of the southern half of the state. A few prairie counties in the southwest part, and the densely wooded counties east of the Mississippi River, however, received very few settlers prior to 1870. Immediately after the Civil War railroad extension became rapid, and by the early 1870's railroads had been extended to the western and southwestern parts of the state and on into the Dakotas. The line from St. Paul to Duluth also connected the agricultural district with this Great Lakes port, and other lines from the western part of the state were soon connected with Duluth.

Although settlement started in the forested portion of Minnesota, that part has now a smaller percentage of improved land than the prairie portion of the state. The prairie counties usually have from 70 to 85 per cent classed as improved land, while the older settled forested counties, such as Wright, Hennepin, and Carver have but little more than half their area classed in the census of 1910 as improved land. There has been, however, a steady increase in the percentage of improved land in the forested counties, thus showing there is not an abandonment of farming but merely a slow development due in large part to the difficulty of clearing the land.

It is in the forested areas that swamp lands are most extensive, and they as well as the forests greatly check the development of agriculture. The most extensive swamps and marshes in the southern half of Minnesota are found in the district east of the Mississippi River, in Pine, Kanabec, Mille Lacs, Isanti, and Anoka counties. In the forested district west of the Mississippi there are numerous lakes, some of which have marshy borders. There are also basins deeply filled with peat inclosed among the morainic hills and ridges. Systematic ditching after careful surveys should greatly decrease the amount of swamp land. In some of the prairie counties, lakes which are represented on the land survey plats, and which still appear on the county atlases, have in many places been completely drained and their beds been converted into agricultural land.

The table, on page 61, compiled from census reports gives the growth of agriculture in each county in the southern half of the state decade by decade from 1870 to 1910.

RANK OF DIFFERENT CROPS IN MINNESOTA

As shown by the census of 1910, the acreage of cereals in Minnesota has the following order from highest to lowest: Wheat, oats, corn, barley, rye. The amount of tame grass cut is but little more than that of wild grass, there being 2,885,987 tons of tame grass, and 2,714,121 tons of wild grass cut in 1909. The acreage of wild grass was but slightly higher than that of the tame grass, there being 1,815,250 acres of tame grass, and 1,988,664 of wild grass.

Wheat leads in 32 of the 63 counties here reported on in the southern part of the state, while oats leads in 20 of them. Corn leads in 5 counties, Anoka, Freeborn, Hennepin, Houston, and Sherburne counties, all in the southeast part of the state. Barley leads in Dodge, Goodhue, Lincoln, Olmsted, Wabasha, and Winona counties, all but one in the southeast part of the state. Wheat leads in the great till plains of the Wisconsin

Per Cent of Improved Land of Counties in Southern Half of Minnesota by Decades, 1870 to 1910

County	1870	1880	1890	1900	1910	Dominant Soil and Vegetation
Aitkin	*	*	0.20	1.77	2.97	Several soils. Mixed forest.
Anoka	2.87	12.80	14.10	29.64	34.50	Sand, mixed gray drift. Scrub oak, wire grass.
Benton	0.98	7.10	19.00	31.10	42.00	Clayey red drift. Hardwood.
Big Stone	*	7.00	32.66	77.56	77.22	Clayey gray drift. Prairie.
Blue Earth	21.00	55.25	77.96	74.66	73.60	Clayey gray drift. Prairie and hardwood.
Brown	8.63	35.78	61.43	80.03	78.56	Clayey gray drift. Prairie.
Carver	14.15	38.67	41.23	50.03	53.40	Mixed and clayey gray drift. Oak.
Chippewa	1.12	16.90	34.22	81.88	79.28	Clayey gray drift. Prairie.
Chisago	2.93	11.40	15.90	31.20	38.33	Clayey gray drift, sand. Hardwood.
Cottonwood	0.19	17.00	33.64	33.40	82.70	Clayey gray drift. Prairie.
Crow Wing‡	*	0.40	3.70	5.30	7.67	Several soils. Mixed forest.
Dakota	42.39	60.26	61.80	71.08	67.77	Gravelly red drift. Oak and prairie.
Dodge	26.47	68.87	68.12	78.00	80.45	Clayey old gray drift. Prairie.
Douglas	3.37	17.30	28.59	46.31	52.95	Mixed gray drift. Hardwood and prairie.
Faribault	14.78	48.88	68.74	85.62	83.46	Clayey gray drift. Prairie.
Fillmore	33.33	65.00	63.74	70.09	70.42	Loess, clayey old gray drift. Oak and prairie.
Freeborn	14.70	54.45	58.11	72.84	69.79	Clayey to mixed gray drift. Prairie, oak groves.
Goodhue	44.21	70.95	73.95	76.30	73.30	Loess, clayey old gray drift. Oak and prairie.
Grant	0.24	9.20	32.73	62.04	72.74	Clayey gray drift, part lake sediment. Prairie.
Hennepin	18.00	39.46	39.24	54.63	52.43	Mixed gray drift. Hardwood.
Houston	18.60	40.00	42.76	46.55	47.72	Loess, residual, alluvial. Oak.
Isanti	2.70	9.20	13.60	30.31	38.72	Sand, mixed gray drift. Oak.
Jackson	1.20	13.50	27.08	78.85	78.96	Clayey gray drift. Prairie.
Kanabec	*	0.20	1.00	4.00	10.95	Clayey to mixed red drift. Mixed forest.
Kandiyohi	1.21	30.79	41.46	66.67	72.14	Clayey to mixed gray drift. Prairie and groves.
Lac qui Parle	*	11.20	41.58	77.44	79.77	Clayey gray drift. Prairie.
Le Sueur	12.50	74.47	45.54	49.93	54.70	Clayey to mixed gray drift. Hardwood.
Lincoln	†	7.00	29.85	69.40	72.77	Clayey to mixed gray drift. Prairie.
Lyon	†	15.40	31.19	73.76	75.93	Clayey gray drift. Prairie.
McLeod	6.76	43.90	62.74	73.70	75.64	Clayey gray drift. Hardwood.
Martin	4.23	12.00	32.27	83.32	81.93	Clayey gray drift. Prairie.
Meeker	5.42	32.27	38.73	65.00	68.10	Clayey to mixed gray drift. Hardwood.
Mille Lacs	0.48	1.80	2.90	8.40	12.97	Clayey to mixed red drift. Mixed forest.
Morrison	0.48	4.90	9.40	20.28	25.14	Clayey to mixed red drift. Mixed forest.
Mower	14.40	60.55	61.86	86.76	86.00	Clayey old gray drift. Prairie.
Murray	*	6.70	25.36	75.12	78.94	Clayey to mixed gray drift. Prairie and groves.
Nicollet	18.00	63.00	71.24	73.80	66.88	Clayey gray drift. Prairie.
Nobles	*	14.70	34.45	64.54	83.98	Clayey gray drift. Prairie.
Olmsted	47.40	75.17	73.02	76.81	74.12	Loess, clayey old gray drift. Oak and prairie.
Otter Tail‡	0.28	10.10	23.84	38.72	45.46	Mixed gray drift. Prairie, mixed forest.
Pine	*	0.20	0.50	3.40	7.17	Several soils. Mixed forest.
Pipestone	*	7.30	29.23	69.38	83.50	Clayey gray drift, partly old. Prairie.
Pope	2.85	18.00	35.82	64.60	64.58	Mixed gray drift. Prairie and groves.
Ramsey	9.92	24.01	22.36	37.97	40.00	Mixed red drift. Oak.
Redwood	†	11.60	26.30	74.13	75.76	Clayey gray drift. Prairie.
Renville	1.55	15.20	36.71	80.00	82.00	Clayey gray drift. Prairie.
Rice	30.00	53.06	69.46	71.90	72.38	Mixed gray drift. Hardwood, prairie.
Rock	*	20.98	45.29	84.92	86.00	Loess, clayey old gray drift. Prairie.
Scott	20.00	42.09	53.71	52.64	56.94	Clayey to mixed gray drift. Hardwood.
Sherburne	2.75	13.70	21.53	30.90	38.65	Mixed gray drift, sand. Scrub-oak.
Sibley	8.35	33.11	61.43	74.42	76.14	Clayey gray drift. Prairie and hardwood.
Stearns	6.33	21.41	28.69	48.23	51.86	Several soils. Hardwood, prairie.
Steele	17.27	69.96	77.23	82.25	81.68	Clayey to mixed gray drift. Prairie.
Stevens	0.27	18.00	25.09	69.02	73.25	Clayey gray drift. Prairie.
Swift	1.12	17.00	27.18	72.50	76.36	Clayey to mixed gray drift. Prairie.
Todd	0.61	7.80	11.40	24.65	32.85	Clayey to mixed red and gray drifts. Mixed forest.
Traverse	*	4.50	27.44	73.33	83.73	Lake silt and sand, clayey gray drift. Prairie.
Wabasha	39.45	61.01	62.80	65.86	66.37	Loess, alluvial. Oak, prairie.
Waseca	17.85	64.36	72.46	81.61	74.88	Clayey gray drift. Prairie, hardwood.
Washington	19.08	41.03	46.71	57.40	60.14	Clayey to mixed red drift. Oak.
Watonwan	6.02	21.90	46.85	78.68	81.27	Clayey to mixed gray drift. Prairie.
Wilkin	0.19	4.20	17.80	56.14	66.76	Lake sediment, clayey gray drift. Prairie.
Winona	33.48	53.88	53.96	56.58	58.29	Loess, alluvial. Prairie, oak.
Wright	5.34	22.47	28.77	48.71	53.73	Clayey to mixed gray drift. Hardwood.
Yellow Medicine	†	14.40	37.84	73.64	78.93	Clayey to mixed gray drift. Prairie.

* Less than one square mile improved in 1870.
† Several counties combined with Redwood County, with 1,074 acres improved land in whole area.
‡ Part of county in northern half also included.

drift bordering the Minnesota valley, and in most of the older settled counties in central Minnesota. Oats leads in the poorly settled counties of eastern Minnesota, and in 7 counties of southwestern Minnesota. In the tables under each county the order of importance of each cereal is given, from highest to lowest.

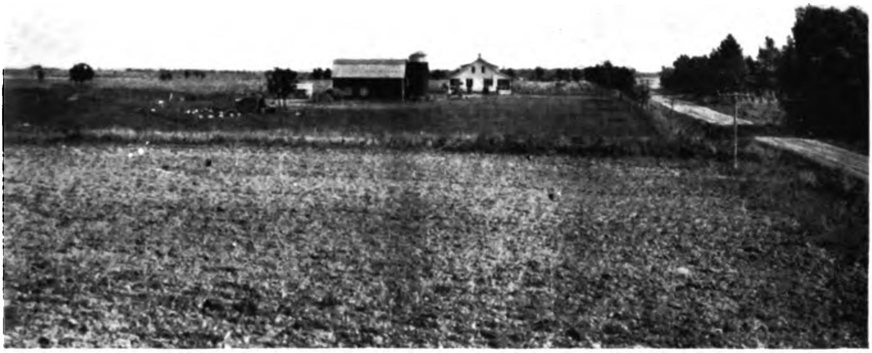
RELATION OF CROP VALUES TO FARM INVESTMENTS IN SOUTHERN MINNESOTA

The gross income from crops, as given by the census of 1910, and as quoted in the tables in connection with each of the counties here discussed, shows a range in the different counties from about 9 per cent to 17 per cent of the total value of the farm property in the respective counties. The following table gives the percentage for each county:

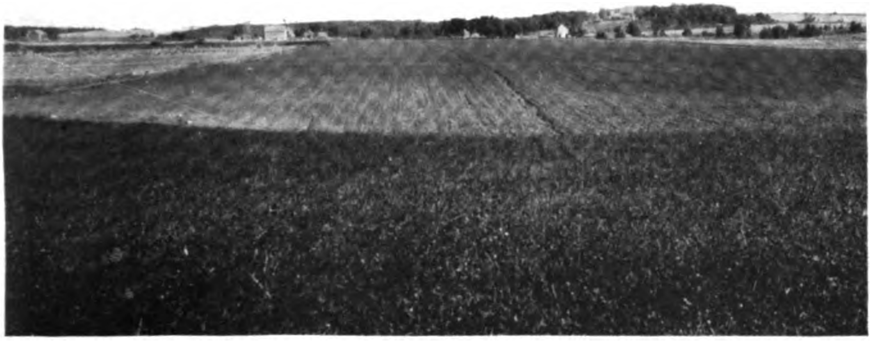
Annual Gross Income of Crops in Per Cent of Farm Values

	Per cent
Big Stone, Pope, Stevens, Swift	17
Chippewa, Grant, Renville, Traverse	16-16.7
Douglas, Isanti, Kandiyohi, Lac qui Parle, Meeker, Stearns, Wilkin	15-15.8
Benton, Morrison, Nicollet, Sherburne, Sibley, Wabasha, Yellow Medicine	14-14.7
Brown, Dakota, Steele, Washington	13-13.9
Blue Earth, Chisago, Goodhue, Le Sueur, McLeod, Mille Lacs, Rice, Scott, Todd, Waseca, Winona, Wright	12-12.9
Anoka, Carver, Cottonwood, Freeborn, Hennepin, Houston, Lincoln, Lyon, Olmsted, Pine, Ramsey, Watonwan	11-11.9
Dodge, Faribault, Fillmore, Jackson, Martin, Mower, Pipestone	10-10.5
Kanabec, Murray, Nobles, Rock	9- 9.7

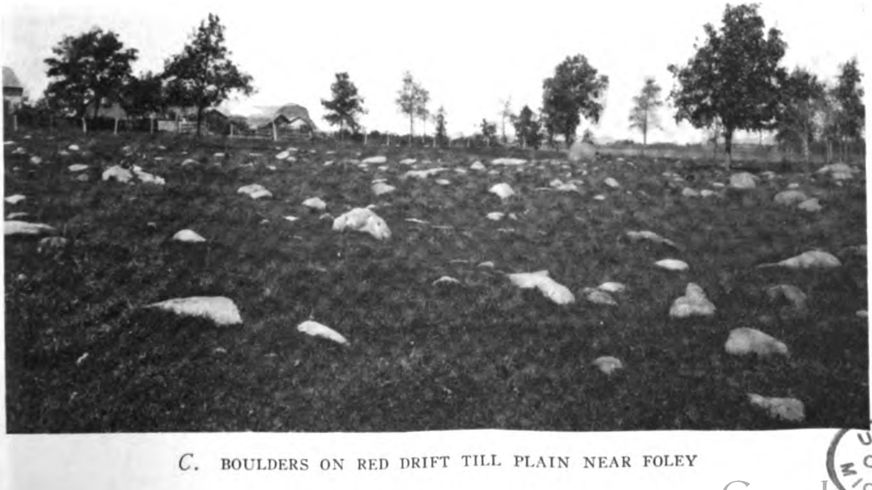
In 8 counties in the southwest part of the state the gross income is 16 to 17 per cent, but in 3 others, also in the southwest part, it is less than 10 per cent. This difference is not a difference in productivity of soil, but seems due largely to the higher estimate of value of land in these 3 counties. It serves to show that prices in these counties have reached, if they have not already gone beyond, profitable use by the present occupants, for the gross income is ordinarily more than double the net income, or real return for farm investments. There are 7 more counties in the southern part in which the gross income is only 10 to 10.5 per cent of the valuation. A large number of counties scattered over the southern half of the state have a gross income between 11 and 16 per cent.



A. CULTIVATED RED DRIFT TILL PLAIN NEAR FOLEY



B. RED DRIFT TILL PLAIN WITH FOREST NEAR FOLEY



C. BOULDERS ON RED DRIFT TILL PLAIN NEAR FOLEY

UNIV. OF MICH.

CHAPTER IV

DESCRIPTIONS OF COUNTIES

In the description of counties which follows, the county taken first is in the northeast corner of the area, and after this counties to the west and south to the southern border of the state are discussed. A few data from the census of 1910 are presented in addition to the results of the land classification on a geologic basis.

PINE COUNTY

Pine County is located in the northeast corner of the area embraced in this report, its eastern boundary being the state line of Minnesota and Wisconsin. Its land area is 1,413 square miles, and the water area of its meandered lakes and streams is 24.76 square miles. It embraces a large amount of poorly drained land classed as swamp on the Land Office plats, there being 387 square miles, or about 27 per cent of the county as computed from these plats. The greater part of this may be readily drained at moderate expense. A few places were noted in the northeast part, however, where the swamps are held in by barriers of rock, and others where prominent drift ridges and knolls inclose them. But in most cases the swamps are due in part to fallen timber and beaver dams which may be easily removed. As a result of the great Hinckley fire which some years ago swept a large tract in the southwest part of the county, the area of some of the swamps was markedly reduced, and peat beds were burned out leaving the soil exposed. In the settlements near Bruno and also near Beroun, the swamp areas have been greatly reduced and rendered tillable. In some cases the swamp lands were pastured for a few years after the water was drained away, and before they were cultivated.

This county is somewhat unique in that it was encroached upon by each of the three ice fields in the Wisconsin stage of glaciation. The Superior ice, however, covered only a narrow strip with red drift along the north border of the county, and the Keewatin ice a few townships of gray drift at the southern end. In the remainder of the county the Patrician red drift is at the surface, and it also underlies the other drifts. There was glacial drainage from the Superior lobe down the Kettle River, from the Patrician ice down the St. Croix River, and from the Keewatin ice along Snake River. The St. Croix also served as an outlet for the glacial Lake Duluth, which produced a large valley with sandy and in part swampy bottoms. The Keewatin or young gray drift at the southern end of the county is largely of clayey texture and high fertility. The red drift is more stony, though much of it has a clayey admixture both in moraines and till plains. It will be likely to be excellent grass land, and the county as a whole may become a profitable region for dairying and stock raising.

Rock hills 10 to 20 feet high, covering a few acres each, are found in the swamps and among the morainic knolls in the northeastern part of the county, and there are rock exposures along the streams in the southern part. The combined area, however, appears to be but little more than 1 per cent of the county.

In the northern part of the county farming is extended but little east of the Great Northern Railroad, but in the southern part it extends over the entire width of the county.

Percentages of Classes of Land in Pine County

	Square miles	Per cent
Sandy red drift moraine with stony loam soil	60	4.2
Clayey red drift moraine. Soil clayey to stony loam	280	19.7
Clayey gray drift moraine, pebbly clay loam soil	20	1.4
Red drift till plain, chiefly stony loam soil	290	20.5
Gray drift till plain, pebbly clay loam soil	58	4.1
Red drift till plain, sandy loam soil	100	7.1
Red drift outwash, sandy to gravelly loam	137	15.8
Glacial drainage and valley alluvium, sandy	87	
Rocky areas	15	1.1
Swamp	366	25.9
	1,413	99.8

Farm and Crop Data for Pine County from Census of 1910

Rural population 10,627 or 7.5 per square mile.

Per cent of land in farms	25.5
Per cent of farm land improved	28.1
Average acres per farm	111.7
Average improved acres per farm	31.3
Value of all farm property	$7,453,287
Per cent of increase 1900 to 1910	227.8
Value of all crops in 1909	$846,136
Cereals (oats, corn, wheat, barley, rye)	$189,951
Other grains and seeds	$5,047
Hay and forage*	$362,443
Vegetables	$158,461
Fruits and nuts	$4,042
All other crops	$126,192

* Tame grass, 32,050 tons; wild grass, 13,356 tons.

SOUTHERN AITKIN COUNTY

The part of Aitkin County south of the median line of the state was briefly discussed with the main part of the county lying north of this line, in Bulletin 13. The per cent of swamp land in this part is somewhat less than for the entire county, estimated by Ralph as 42 per cent. The swamps are largely underlain by clayey till similar to that of the bordering dry land, and they can be greatly reduced by systematic ditching. Two sandy areas occur in this part of the county, one being immediately north of Mille Lacs Lake, and the other at the terminus of the Superior lobe in T. 45, R. 24, and T. 45, R. 23W., with an extension down Snake River into T. 44, R. 23W.

This part of the county is traversed by a new branch of the Soo Railroad, on which the villages of Arthyde, Solana, McGrath, and Red Top have sprung up, while farms are being rapidly developed. For statistics from the census of 1910 concerning the products of this county, reference may be made to Bulletin 13.

KANABEC COUNTY

Kanabec County is located in eastern Minnesota with Mora as the county seat. The principal settlement and farming development is along or near the lines of the Great Northern Railroad, one of which crosses its southern part and another touches its southwest corner. The surface of the county slopes from north to south, being 1,200 to 1,300 feet in the northern part and about 950 feet in the southern. The prominent moraine of red Patrician drift which crosses the northern part of Mille Lacs County also passes through the northern edge of this county, but elsewhere morainic features are weak and much of the surface is a till plain. There are a few outcrops of rock with slight relief in the northern part of the county, but these are chiefly along or near Snake River.

The Grantsburg lobe of the Keewatin ice field barely touched the southern edge of the county for a few miles west of Braham. A small glacial lake covered much of the southeast township. This lake, however, was apparently held up by the Patrician ice barrier on the north. This lake area was later encroached upon from the south by the Keewatin ice. It has a clay soil.

Another small glacial lake extended into the southwest corner of the county from southern Mille Lacs County. This seems to have been held in by the Keewatin ice south of it which covered the lower course of Rum River, the present outlet for this region.

Interglacial valleys cut in the old gray drift which underlie this county have been only partly filled by the later or Wisconsin drift. Lakes and swamps occur along the lines of these partially filled valleys, and gravelly knolls also occur in them.

Percentages of Classes of Land in Kanabec County

	Square miles	Per cent
Sandy moraine, sandy to stony loam	25	4.7
Clayey moraine, clayey to stony loam	55	10.3
Clayey to mixed till plain, clayey to stony loam	346	64.8
Gravelly land, knolly and plain	20	3.7
Lake clay	20	3.7
Rock outcrops	3	0.5
Swamp	65	12.3
	534	100.0

Farm and Crop Data for Kanabec County, from Census of 1910

Rural population 5,110 or 9.5 per square mile.	
Per cent of land in farms	34.1
Per cent of farm land improved	32.1
Average acres per farm	114.4
Average improved acres per farm	36.7
Value of all farm property	$4,698,416
Per cent increase, 1900 to 1910	209.8
Value of all crops in 1909	$447,255
Cereals (oats, corn, wheat, barley, rye)	$96,036
Other grains and seeds	$1,891
Hay and forage*	$197,218
Vegetables	$112,007
Fruits and nuts	$1,754
All other crops	$38,349

* Tame grass, 19,445 tons; wild grass, 8,644 tons.

MILLE LACS COUNTY

Mille Lacs County embraces the southern end of Mille Lacs Lake and extends southward about 40 miles beyond the lake in a narrow strip 12 to 18 miles wide. The land area is 583 square miles and the water area 117 square miles. The percentage of swamp land is about the same as in Kanabec County, or not far from one eighth of the county. The northern part of the county is crossed by a prominent moraine of red Patrician drift, but the remainder is largely till plain of red Patrician drift. A moraine of the Keewatin gray drift is found in the south end of the county. In this southern end there was a small glacial lake immediately north of the Keewatin ice border whose bed is now drained southward by Rum River.

There are a few places where granite ledges are exposed along and near Rum River and its tributaries. They have slight relief above the land around them, and a combined area of not over 2 square miles.

As in Kanabec County the interglacial valleys cut in the old gray drift are only partly filled by the later or Wisconsin drift, and are now occupied to some extent by swamps and lakes. The moraine of red Patrician drift also incloses many lakes and swamps.

The principal settlements and most of the farming development has been along and near the Great Northern Railway lines in the southern part of the county, and along the border of Mille Lacs Lake, near the Soo Railway.

Percentages of Classes of Land in Mille Lacs County

	Square miles	Per cent
Clayey to mixed red drift moraine, stony loam	80	13.72
Clayey gray drift moraine, pebbly clay loam	5	0.86
Clayey to mixed red drift till plain, chiefly stony loam	356	61.07
Clayey gray drift till plain, pebbly clay loam	5	0.86
Gravelly and sandy outwash and glacial drainage, sandy to gravelly loam	35	6.00
Glacial lake clay	20	3.43
Rock outcrops	2	0.34
Swamp lands	80	13.72
	583	100.00

Farm and Crop Data for Mille Lacs County from Census of 1910

Rural population 2,411 or 4 per square mile.	
Per cent of land in farms	33.1
Per cent of farm land improved	39.2
Average acres per farm	96.8
Average improved acres per farm	37.9
Value of all farm property	$5,599,111
Percentage of increase, 1900 to 1910	169
Value of all crops in 1909	$680,497
Cereals (oats, corn, wheat, barley, rye)	$178,259
Other grains and seeds	$4,300
Hay and forage*	$251,558
Vegetables, chiefly potatoes	$184,748
Fruits and nuts	$3,125
All other crops	$58,507

* Tame grass, 28,784 tons; wild grass, 12,904 tons.

SOUTHERN CROW WING COUNTY

Crow Wing County, of which Brainerd is the county seat, is near the center of the state, and is so situated that part of its area lies in the northeast quarter, part in the northwest quarter, and about 40 per cent in the southern half of the state. Descriptions of the northern part have been given in Bulletins 12 and 13.

Crow Wing County is drained entirely by the Mississippi River which traverses it nearly centrally from northeast to southwest. A large part of the county stands between 1,200 and 1,300 feet above sea level, there being only a few square miles above 1,300 feet and only narrow strips along the valleys below 1,200 feet. The prominent Mille Lacs moraine traverses the eastern part of the county. West of it, occupying several townships in the southern part of the county, is a till plain with gently undulating surface and rich clayey to sandy loam soil. East of the river above Brainerd there is a diffuse morainic belt. Along and west of the Mississippi River there are sandy and gravelly plains which are very sparsely settled. Fine sand from these plains has drifted to some extent over the till plains immediately south of Brainerd, forming a coating from a few inches to several feet thick for a distance of one to three miles east of the valley.

The moraines of the southern part of the county are largely of gravelly and stony drift, while the outwash aprons associated with them are also of light sandy soil.

Of about 400 square miles in this southern part of Crow Wing County, there are 130 square miles of clayey till lying southeast of Brainerd which includes most of the farm land of this part of the county.

SOUTHERN CASS COUNTY

About 140 square miles of the southern end of Cass County falls south of the median line of the state. The remainder of the county is discussed in Bulletin 12. Of this southern part about 40 square miles are till plain with clayey to stony loam soil. About 25 square miles are rugged moraine with gravelly and loose textured drift. The remaining 75 square miles are occupied by gravelly and sandy outwash plains on the borders of Crow Wing River. The principal settlement is on the till upland, but a few small farms are opened on the plains in the Crow Wing valley along the line of the Northern Pacific Railroad in the vicinity of Sylvan and Pillager stations.

MORRISON COUNTY

Morrison County is located in the central part of Minnesota with Little Falls as the county seat. The Mississippi River crosses the county from north to south a little west of the center and Crow Wing River forms part of its north border. There is a broad belt of sandy land along the Mississippi, formed as a glacial drainage from districts farther north. There is another plain of sandy gravel with a somewhat more loamy soil which lies a few miles east of the Mississippi River in the southern part of the county. There is also a sandy plain along Crow Wing River. The greater part of the county is a till plain which is encircled on the west by a prominent red drift moraine which occupies the northwestern part of this county and the eastern part of Todd County. This moraine is very complex and has small outwash aprons, as well as lakes and swamps enclosed among its ridges and knolls. Owing to the roughness of the surface and the stony character of the drift, this moraine has remained largely undeveloped, while the neighboring till plains have become more fully settled. The till plains of the eastern part of the county, however, are only partly settled, but this is due largely to the lack of railroad facilities prior to the recent construction of a branch of the Soo Line Railroad across the southeast part of the county.

The till plains of this county, like those of Mille Lacs and Kanabec counties, have so thin a coating of the Wisconsin red drift that the interglacial valleys cut in the old gray drift are only partly filled, and exposures of the old gray drift beneath the red drift are not rare along the streams and bluffs.

The percentage of swamp land in this county is very much smaller than in counties to the north and east, there being, as estimated by Ralph, only 20,000 acres or 31 square miles, which is but 2.7 per cent of the county.

Rock outcrops are not extensive though exposures are not infrequent. There is probably an area of less than 10 square miles in which the rock is close to the surface.

Several sharp gravel ridges, or eskers, are found on the till plain or leading into the edge of the moraines. One such ridge leads past Darling Station along or near the Northern Pacific Railroad, northwest of Little Falls, for a distance of about 7 miles. It has been extensively drawn upon for railroad ballast. Another gravel ridge southeast of Fort Ripley, on the east side of the Mississippi, is 5 or 6 miles long, and a shorter one is found two miles farther south near Topeka. There is also a short gravel ridge south of Motley in the northwest part of the county. All such ridges are of much value in furnishing road material, especially when located in till plains.

Fine sand blown from the outwash and river gravels along the Mississippi extends the sandy soil areas eastward even onto the upland. Such a dune-sand tract lies southeast of Fort Ripley, a larger one east of Royalton, and a small area at Little Falls.

Percentages of Classes of Land in Morrison County

	Square miles	Per cent
Moraine with sandy to gravelly loam soil	175	15.31
Moraine with pebbly clay loam soil	70	6.12
Eskers, or gravelly ridges, stony loam soil	2	0.18
Outwash gravel plains and sandy river bottoms	180	15.75
Till plain with pebbly clay loam soil	500	43.75
Till plain with mixed soil	170	14.87
Swamps	36	3.15
Area with rock near surface	10	0.87
	1,143	100.00

Farm and Crop Data for Morrison County from Census of 1910

Rural population 15,433 or 13 per square mile.

Percentage of land area in farms	51.2
Per cent of farm land improved	49.1
Average acres per farm	142.9
Average improved acres per farm	70.2
Value of all farm property	$13,696,359
Per cent of increase, 1900 to 1910	121.6
Total value of crops in 1909	$1,901,837
Cereals (wheat, oats, corn, barley, rye)	$1,250,520

Farm and Crop Data for Morrison County (Continued)

Other grains and seeds	$51,754
Hay and forage*	$335,221
Vegetables	$149,684
Fruits and nuts	$4,937
All other crops	$109,757

* Tame grass, 31,746 tons; wild grass, 45,667. Each yielded about 1.5 tons per acre.

TODD COUNTY

Todd County is located in the west central part of Minnesota with Long Prairie as the county seat. The drainage of about two thirds of the county is northward to Crow Wing River, chiefly through Long Prairie River. The southern end of the county is drained southward to Sauk River, and part of the eastern edge is drained eastward to the Mississippi chiefly by Swan River. Hardwood forest occupied the south part, and mixed hardwood and conifers the north part. There were small prairies on gravel plains near Long Prairie and Round Prairie.

The most prominent topographic feature is a strong and sharply ridged red drift morainic system in the east part of the county. It covers a width of 3 to 6 miles, and contains ridges 50 to 75 feet or more in height as well as numerous basins and small lakes. This morainic system is very sparsely settled in comparison with the remainder of the county.

The Keewatin ice field apparently had its eastern limit along or near the west base of this prominent morainic system, but its drift is thin in this county and generally plain. It includes a sharp morainic ridge running from Long Prairie southwestward to Osakis Lake, which is scarcely one fourth mile in average width, but rises 50 to 75 feet or more above the bordering plains.

The till plains of this county have a relatively thin veneer of young or Wisconsin drift over a much eroded surface of old gray drift. The present drainage lines, therefore, usually follow broad swales marking the courses of interglacial streams. The sandy outwash plains and lines of glacial drainage also occupy or follow the courses of interglacial drainage to some extent.

A red drift till plain lies between two red drift moraines in the southeast part of the county in the vicinity of Gray Eagle. A till plain on the east of the main moraine extends slightly into Todd County, but lies mainly in Morrison County. These till plains are largely under cultivation. The soil is usually a clayey to stony loam.

Attention is directed in the introductory chapter to the peculiar mixture of red drift rocks and gray drift in a belt immediately west of the prominent moraine. This is a loose textured, rather stony till, yet it has a sufficient amount of clay to be very productive.

The amount of swamp land or land too wet to cultivate is estimated by Ralph to be 25,000 acres, or about 40 square miles, which is slightly more than 4 per cent of the area of the county. Much of this is in sandy plains in the northeast corner and in the western edge of the county. But some of the swales in the till area where the interglacial valleys are imperfectly filled by the Wisconsin drift have strips of wet land. There are also small swamps inclosed among the morainic knolls and ridges.

Per Cent of Classes of Land in Todd County

	Square miles	Per cent
Red drift moraines with sandy to gravelly loam soil	184	19.23
Gray drift moraine with sandy to gravelly loam soil	6	.63
Gray drift moraine with pebbly clay loam soil	60	6.27
Outwash gravel plains and sandy bottoms	125	13.05
Red drift till plains, clayey to sandy and pebbly soil	58	6.05
Gray drift till plains, mainly pebbly clay loam soil	484	50.57
Swamps and wet lands	40	4.20
	957	100.00

Farm and Crop Data for Todd County from Census of 1910

Rural population 16,588 or 17.3 per square mile

Percentage of land area in farms	69.3
Per cent of farm land improved	47.4
Average acres per farm	141.7
Average improved acres per farm	67.2
Value of all farm property	$15,854,493
Per cent increase, 1900 to 1910	88.2
Total value of crops in 1909	$1,971,992
Cereals produced (oats, wheat, corn, barley, rye)	$1,223,557
Other grains and seeds	$40,506
Hay and forage*	$395,985
Vegetables	$181,053
Fruits and nuts	$9,484
All other crops	$121,407

* There were 41,864 tons of cultivated and 48,397 tons of wild grasses cut. The cultivated grasses yielded about 1.7 tons per acre and the wild grasses 1.4 tons.

SOUTHERN OTTER TAIL COUNTY

Otter Tail County is located in the western part of Minnesota with Fergus Falls as the county seat. It has a land area of over 2,000 square miles not including 200 square miles of lake area. The northern part of the county embracing 35 townships, or an area of about 1,260 square miles, was described in Bulletin 12. There remain 27 townships, or about 972 square miles in the southern part to be here discussed.

The entire area is settled about as fully as is consistent with profitable agriculture under present methods. There is a large amount of rough moraine with included bogs and lakes that is now in woodland pasture. In the prairie portion, which embraces a few townships in the southwest part of the county, nearly all of the land that is dry enough has been brought under cultivation.

The greater part of the southern half of Otter Tail County is drained westward through Otter Tail River and its branches to the Red River valley. The eastern part is drained northeastward into Crow Wing

River and thence into the Mississippi. Lakes are a conspicuous feature in nearly every township, but are very small in the western range of townships.

The most prominent topographic feature is the intricate system of moraines which was formed on the east side of the Keewatin ice field, as noted in the general discussion of the features of that ice field. There are only narrow strips of till plain in the county. The total area of till plain in the three southern tiers of townships is estimated to be 160 square miles, or 16.5 per cent of the area. The greater parts of the moraines of this county have a sandy to gravelly loam soil, but those in the western part in the prairie portion of the county have a clay loam soil.

About 50 square miles along the western edge of the county were covered by the waters of the glacial Lake Agassiz. The surface here is very flat and the soil is largely a silty loam or fine sand. The shore lines of the lake are of fine gravel suitable for road ballast.

There are two very extensive outwash plains, each with an area of several townships, associated with the moraines in this county. One in the eastern part, known as the Parkers Prairie Plain, has an altitude of 1,450 to 1,500 feet, and slopes northeastward to Crow Wing River. It is an outwash from a prominent moraine, known as the Leaf Hills, which runs along its western border, and from which a very prominent spur, known as Leaf Mountain, extends southwestward to Christina Lake.

To the west of the Leaf Hills there is a narrow till plain succeeded by another extensive outwash plain which surrounds Otter Tail and Battle lakes and which was formed as an outwash from the great morainic system lying west of it. These outwash plains have a rather light sandy loam soil, but they were among the earliest areas in the county to be farmed, and are still yielding good returns under skillful management.

DOUGLAS COUNTY

Douglas County is situated in western Minnesota with Alexandria as the county seat. Its land area is 648 square miles, and its lakes, which are very numerous, are estimated to occupy 72 square miles. The eastern part of the county is drained northeastward through Long Prairie River to Crow Wing and thence to the Mississippi; but the remainder of the county slopes southwestward and drains in that direction to the Chippewa, which flows southward into Minnesota River. The greater part of this county was timbered with hardwood, but prairie extended into its western edge.

The western half of the county is very largely occupied by a prominent morainic system which formed along the east side of the Keewatin ice sheet. There are extensive outwash plains of sandy gravel along the eastern edge of this morainic system. Farther east there are till plains which extend into Todd County. These, as well as the morainic system, have a sheet of young gray drift formed by the Keewatin ice field.

The morainic areas as well as the till plains are largely under cultivation, and they are chiefly of clayey till with pebbly clay loam soil. The gravel plains have a light sandy loam soil. They are largely under cultivation, and except in very dry seasons have a good yield of cereals.

Percentages of Classes of Land in Douglas County

	Square miles	Per cent
Moraine with sandy to gravelly loam soil	75	11.59
Moraine with pebbly clay loam soil	288	44.44
Outwash gravel and sand plains	135	20.83
Till plains with prevailing clay loam soil	150	23.14
	648	100.00

Farm and Crop Data for Douglas County from Census of 1910

Rural population 12,165 or 18.8 per square mile

Per cent of land area in farms	85.4
Per cent of farm land improved	62.0
Average acres per farm	156.5
Average improved acres per farm	97.0
Value of all farm property	$16,312,224
Per cent of increase, 1900 to 1910	97.2
Value of all crops in 1909	$2,432,300
Cereals (wheat, oats, barley, corn, rye)	$1,175,703
Other grains and seeds	$97,751
Hay and forage*	$310,268
Vegetables	$65,971
Fruits and nuts	$10,250
All other crops	$73,522

* Tame grass, 38,775 tons; wild grass, 43,831 tons.

GRANT COUNTY

Grant County is situated in the western part of Minnesota with Elbow Lake as the county seat. This is a prairie county with only narrow fringes of timber along lakes and streams. The eastern part of the county is drained southward through the Pomme de Terre and Chippewa rivers to the Minnesota. The western part is drained westward through Mustinka River to Lake Traverse, and thence northward by Red River to Hudson Bay.

About 128 square miles in the western part of the county were covered by the waters of the glacial Lake Agassiz. The remainder of the county is largely a till plain of young gray drift. The eastern edge is strongly morainic, and there are narrow moraines of feeble expression leading north to south across the county. Narrow strips of gravelly and sandy land border the Chippewa, the Pomme de Terre, and the south flowing part of the Mustinka rivers, which appear to mark lines of glacial drainage. Several of the higher lakes of this county have been drained by deep ditching and their beds converted into farm land. Several others of the lakes are in the bottom of valleys that appear to be partially filled interglacial valleys. Some partly filled valleys are without streams, and these present a rougher topography than the bordering upland, with some likeness to morainic topography, but this topography seems to have been developed locally because of irregularity of the ice movement in its passage across the valleys.

Percentages of Classes of Land in Grant County

	Square miles	Per cent
Moraines chiefly with pebbly clay loam soil	100	18.08
Gravelly outwash and sandy glacial drainage	35	6.33
Till plains with prevailing clay loam soil	290	52.44
Sandy deposits of Lake Agassiz	28	5.06
Clayey deposits of Lake Agassiz	100	18.08
	553	99.99

Farm and Crop Data for Grant County from Census of 1910

Rural population 6,379 or 11.4 per square mile	
Per cent of land area in farms	83.8
Per cent of farm land improved	86.8
Average acres per farm	250.2
Average improved acres per farm	217.2
Value of all farm property	$13,482,322
Per cent of increase, 1900 to 1910	121.4
Value of all crops in 1909	$2,232,674
Cereals (oats, wheat, barley, corn, rye)	$1,835,178
Other grains and seeds	$167,687
Hay and forage*	$198,881
Vegetables	$23,424
Fruits and nuts	$2,400
All other crops	$5,104

* Tame grass, 23,991 tons; wild grass, 28,738 tons.

WILKIN COUNTY

Wilkin County is on the western edge of Minnesota with Breckenridge as its county seat, and has an area of 745 square miles. With the exception of about 50 square miles in the northeast part it was covered by the waters of Lake Agassiz. Its surface is consequently level and nearly featureless. There is, however, a fall of over 300 feet in crossing the county from east to west along the northern line in a distance of about 25 miles. In the southern end of the county the fall is about 50 feet in a distance of 15 miles. The county had few natural lines of drainage, but side ditches follow nearly all the highways and receive water from tile drains on the farms and carry it to natural drainage lines. Otter Tail River and Rabbit Creek run across the southern part of the county and Deerhorn Creek its northeast corner, while Bois des Sioux and Red River flow on the west border.

The percentages of classes of land in the northern part of the county have been given in Bulletin 12. In that part of the county there are 50 square miles of clayey moraine and till plain, with pebbly clay loam soil, standing above the level of Lake Agassiz. But in the part south of the median line of the state only about 2 square miles of till plains stood above the lake limits. In the northern part there are about 160 square miles of lake-washed drift with pebbly soil and but a slight cover of lake silt, and about 90 square miles covered by lake sand. There thus remain only 70 square miles of that part with sufficiently heavy deposits of lake silt to make a black clay loam soil. In the southern part of the county the lake silt and black clay loam soil form a strip several miles wide bordering Red River and the Bois des Sioux. As one passes eastward the silt thins out gradually, so that clayey till is at the surface, or within reach of the plow, in the eastern part of the county. The soil is somewhat sandy near Foxhome and east of Nashua, but grades into clay loam at the west.

The shore lines of Lake Agassiz are usually gravelly ridges which furnish good building sites and roadways, and were thus used extensively in the early days of settlement. These shore lines, though running for long distances, have an aggregate area of but a few square miles, probably less than 1 per cent of the county.

The census for 1910 reports about 44 square miles of wild grass cut in 1909. This grass was in areas that were still too wet for cultivation. There is probably not more than 100 square miles of poorly drained land remaining in the county, and part of this can be reclaimed by systematic ditching.

Farm and Crop Data for Wilkin County from Census of 1910

Rural population 5,585 or 7.5 per square mile

Per cent of land area in farms	70.5
Per cent of farm land improved	94.7
Average acres per farm	340.8
Average improved acres per farm	322.8
Value of all farm property	$15,832,394
Per cent of increase, 1900 to 1910	118.3
Value of all crops in 1909	$2,415,558
Cereals produced in 1909 (wheat, oats, barley, corn, rye)	$2,010,119
Other grains and seeds	$123,043
Hay and forage*	$187,102
Vegetables	$90,159
Fruits and nuts	$1,464
All other crops	$3,671

* Tame grass, 16,641 tons; wild grass, 25,733 tons.

TRAVERSE COUNTY

Traverse County is situated on the western border of the state with Wheaton as its county seat. It is a prairie county and there is very little land that is not under cultivation. Such land, however, is found along the bluffs and ravines on the borders of Lake Traverse which are too rough to cultivate. There are also several miles of swamp land in the northeast part of the county along the Mustinka valley and between that valley and Tintah which are being reclaimed by ditching. The drainage is nearly all northward to the Red River valley. Mustinka River and its tributaries ramify the eastern part, while Lake Traverse and Bois des Sioux River discharge along the west border to Red River. A few square miles in the southwest corner are tributary to Big Stone Lake and Minnesota River.

Only the southern end of the county stood above the level of Lake Agassiz, and this is occupied by a till plain except two narrow morainic strips which cross the area between Lake Traverse and the south end of the Lake Agassiz area. The western of these moraines has many small knolls and a diversified soil, but the eastern one has a gently undulating surface and a somewhat uniform pebbly clay loam soil similar to that of the bordering till plain.

This county embraces the head of the outlet of Lake Agassiz, and there are channels cut in the bed at the lower levels of the lake along the entire west side of the county and also along the southwest flowing portion of Mustinka River, but in the higher stages the lake opened directly into the large valley now occupied by Lake Traverse. The highest limits of Lake Agassiz waters were 1,065 to 1,070 feet, but the outlet was cut down to about 970 feet during subsequent southward discharge of the lake.

There are very bowldery areas in central and northwestern Traverse County within the limits of the Lake Agassiz. The bowlders were probably dropped in part directly from the shrinking ice border. The erosion of the channels above noted may also have tended to concentrate them.

At the extreme southern end of the Lake Agassiz area in T. 126, Rs. 45 and 46W., and the southeast part of T. 127, R. 45W., there is a coating of fine sandy loam nearly free from pebbles with a depth of 2 to 5 feet, so the till there is seldom exposed. But elsewhere in the county the till in the lake bed is very scantily covered with lake sediment. The northern end of the county has a black clay loam soil, but even there a pebbly clay or till is found at a depth of a few inches.

The shore lines of Lake Agassiz are composed of sandy gravel. There are also gravel bars and small areas of sandy gravel on a high tract between the low channels of the lake crossed by the Milwaukee and St. Paul Railroad just before it passes into South Dakota. Some of these gravel bars are at the level of the Norcross beach, and others at the level of the Tintah beach. The main shore of the Tintah beach follows the east side of the southwest flowing portion of the Mustinka River.

Percentages of Classes of Land in Traverse County

	Square miles	Per cent
Moraine chiefly clayey, with pebbly clay loam soil	36	6.34
Till plain with pebbly clay loam soil	150	26.41
Lake-washed till in bed of Lake Agassiz	240	42.24
Sandy to sandy loam soil in bed of Lake Agassiz	90	15.83
Gravelly beaches and bars	4	0.71
Marshes and bogs	18	3.17
Black clay loam, lacustrine	30	5.28
	568	99.98

Farm and Crop Data for Traverse County from Census of 1910

Rural population 5,286 or 9 per square mile	
Per cent of land area in farms	87.4
Per cent of farm land improved	95.8
Average acres per farm	337.1
Average improved acres per farm	322.9
Value of all farm property	$16,296,339
Per cent of increase, 1900 to 1910	132.0
Value of all crops in 1909	$2,720,072
Cereals (wheat, oats, barley, corn, rye)	$2,333,966
Other grains and seeds	$171,316
Hay and forage*	$176,589
Vegetables	$34,700
Fruits and nuts	$2,535
All other crops	$916

* Tame grass, 21,163 tons; wild grass, 20,681 tons.

BIG STONE COUNTY

Big Stone County is situated on the western border of the state, with Ortonville as the county seat, and has an area of 491 square miles. The drainage is mainly to the Minnesota River, but the northeast corner drains northward to Mustinka River and the Red River of the North. The natural drainage lines are very imperfect and large ditches have been carried along highways to connect with the natural drainage lines. The dividing ridge in the northeast part of the county is 1,170 to 1,180 feet, or fully 100 feet above the highest shore of Lake Agassiz and over 200 feet above Big Stone Lake. It has the appearance of an overridden moraine, for there are numerous basins and swales along it; but the prominent parts have a smooth surface of clayey calcareous till like that of the till plains of this region.

The greater part of Big Stone County is a till plain with pebbly clay loam soil. It is thickly set with small lakes and basins, estimated to occupy about 10 per cent of the surface. There is a morainic belt in the northwest part of the county leading southward past Beardsley to Big Stone Lake. It follows the south side of that lake in South Dakota, but comes back into Minnesota at the southeast end of the lake and traverses the south part of Big Stone County, making a detour northward around the head of a sandy outwash plain east of Odessa. There is an outwash plain along much of its border, both in northwestern and in southern Big

Stone County. The outwash plains stand 50 to 75 feet above the broad bottoms of the Minnesota valley. In places there are islands in the valley with the outwash preserved on them, one of which is to be seen in the village of Odessa, and others farther east.

In the Minnesota valley there are ledges of granite occupying perhaps 10 per cent of its bottoms, around which granite bowlders are numerous over large areas. A considerable part of the valley is also too wet for cultivation.

The soil on the moraines is a loose textured clayey to gravelly loam, and occasional gravel knolls are present. The outwash plains have a rather light sandy soil.

Percentages of Classes of Land in Big Stone County

	Square miles	Per cent
Moraine chiefly of pebbly clay loam soil	75	15.28
Outwash sand and gravel plains (outside Minnesota valley)	52	10.59
Till plains including ponds and basins, largely of pebbly clay loam soil	331	67.41
Minnesota bottoms (including rocky ledges)	33	6.72
	491	100.00

Farm and Crop Data for Big Stone County from Census of 1910

Rural population 5,165 or 10.5 per square mile	
Per cent of land area in farms	90.0
Per cent of farm land improved	85.8
Average acres per farm	294.4
Average improved acres per farm	252.6
Value of all farm property	$14,262,257
Per cent of increase 1900 to 1910	131.8
Value of all crops in 1909	$2,431,452
Cereals (wheat, oats, barley, corn, rye)	$2,074,389
Other grains and seeds	$151,276
Hay and forage*	$158,628
Vegetables	$40,505
Fruits and nuts	$4,491
All other crops	$2,163

* Tame grass, 18,694 tons; wild grass, 34,221 tons.

STEVENS COUNTY

Stevens County lies east of Big Stone and Traverse counties in the western part of the state, with Morris as the county seat. It has a land area of 564 square miles, while small lakes give an additional area of about 12 square miles. The drainage is mainly southward through Pomme de Terre and Chippewa rivers to the Minnesota, but the northwest corner of the county drains northwestward to the Red River drainage.

Pomme de Terre River leads through several lakes. There are also lakes on the uplands each side and in partially filled interglacial valleys. Those on the uplands have in some cases been completely drained by deep ditching, and their beds converted into farm land.

The greater part of the county is a plain of clayey till with black clay loam soil. The surface is somewhat rougher and the character of the soil more variable in some filled interglacial valleys than on the higher and smoother tracts above them.

There is a moraine along part of the east edge of the county. There are also other lines of knolly land suggesting later ice borders in the interior of the county. Strips of gravelly land, formed by glacial drainage, occur along Pomme de Terre and Chippewa valleys, and a sandy plain of considerable extent spreads from southeastern Stevens County east and south into Pope and Swift counties.

A few square miles in the northwest part of the county were covered by Lake Agassiz, and the soil there is sandy with gravelly strips along the shores.

Just outside the limits of Lake Agassiz, there is a narrow strip extending back about to the 1,100 foot contour, which carries a thin deposit of fine sand and silt. This appears to be due to a ponding of the waters along the edge of the ice while it was occupying the low land later covered by Lake Agassiz. Elsewhere in the county the till plains are not covered with such silt, but have a pebbly clay loam soil, much of it of dark color.

Percentages of Classes of Land in Stevens County

	Square miles	Per cent
Moraine chiefly of pebbly clay loam soil	30	5.32
Gravelly and sandy outwash plains	35	6.20
Sandy loam of ponded waters	35	6.20
Sand and gravel of Lake Agassiz shores and bed	4	0.71
Till plain chiefly of pebbly clay loam soil	460	81.56
	564	99.99

Farm and Crop Data for Stevens County from Census of 1910

Rural population 5,480 or 9.7 per square mile	
Per cent of land area in farms	84.5
Per cent of farm land improved	86.7
Average acres per farm	300.4
Average improved acres per farm	260.6
Value of all farm property	$13,774,191
Per cent of increase 1900 to 1910	107.0
Value of all crops in 1909	$2,335,888
Cereals (wheat, oats, barley, corn, rye)	$1,914,060
Other grains and seeds	$143,209
Hay and forage*	$236,594
Vegetables	$37,173
Fruits and nuts	$1,699
All other crops	$3,153

* Tame grass, 27,353 tons; wild grass, 27,959 tons.

POPE COUNTY

Pope County is located in the west central part of the state, with Glenwood as the county seat. It embraces 20 townships or about 720 square miles, of which 27 square miles are in lakes, leaving a land area of 693 square miles. Lake Minnewaska, on the shores of which Glenwood stands, covers an area of about 13 square miles.

The drainage is nearly all southward and southwestward through Chippewa River and its tributaries to the Minnesota; but the eastern edge of the county is drained eastward, partly by Sauk River and partly by Crow River to the Mississippi.

In Pope County the great morainic system formed on the east side of the Keewatin ice field turns from a southward to an eastward course, and a very extensive outwash apron occupies this angle outside the morainic system. It covers several townships in the east part of Pope County, and in southwestern Stearns and northern Kandiyohi counties. This outwash plain is very elevated, its highest part being above 1,400 feet, and it slopes northeastward to about 1,300 feet at its eastern edge. Only a small part of the great morainic system is as elevated as this outwash area. In the western part of the county there is a moraine which follows down Chippewa valley, and this has an outwash plain covering the southwest part of the county, which stands 1,050 to 1,100 feet. A narrow till plain in western Pope County lies between this moraine and the large morainic system to the east. There is also a till plain east of the great outwash plain in the northeast part of Pope County.

There is some rough land in the morainic areas with very stony soil, and the drift is loose textured and gravelly for a short distance next to the outwash plain. But a large part of the great morainic system has a pebbly clay loam soil. The till plains have a somewhat uniform pebbly clay loam soil. The outwash plains of eastern Pope County have a light sandy soil, but there are boggy depressions of considerable extent scattered over it which contain muck and peat. The sandy plain of the southwest corner of the county has a light soil, and it also is traversed by boggy depressions with mucky soil.

Percentages of Classes of Land in Pope County

	Square miles	Per cent
Moraine, chiefly of pebbly clay loam soil, with included boggy land	300	43.29
Gravelly and sandy outwash plains with included bogs	200	28.86
Till plains with mixed soil, partly sandy and gravelly	38	5.48
Till plains chiefly with pebbly clay loam soil	155	22.37
	693	100.00

Farm and Crop Data for Pope County from Census of 1910

Rural population 9,157 or 14.65 per square mile

Per cent of land area in farms	84.2
Per cent of farm land improved	76.7
Average acres per farm	226.4
Average improved acres per farm	173.7
Value of all farm property	$15,479,163
Percentage of increase 1900 to 1910	103.0

Farm and Crop Data for Pope County (Continued)

Value of all crops in 1909	$2,631,079
Cereals (wheat, oats, barley, corn, rye)	$2,079,901
Other grains and seeds	$195,565
Hay and forage*	$292,491
Vegetables	$38,283
Fruits and nuts	$6,589
All other crops	$18,250

* Tame grass, 33,219 tons; wild grass, 46,050 tons.

STEARNS COUNTY

Stearns County is located in the south central part of the state, with St. Cloud as the county seat. The entire county drains eastward to the Mississippi which forms its eastern boundary. Sauk River is the main drainage line within the county, but the southwest part is drained by Crow River, and the southeast and the northeast parts by smaller drainage lines directly tributary to the Mississippi.

The eastern part of the county has a prominent morainic system of the Patrician red drift, as well as till plains and outwash plains of red drift. But the central and western parts are covered by the Keewatin gray drift which overlaps the western edge of the red drift. The gray drift also covers the southern edge of the county clear out to the Mississippi. Its border crosses that stream 6 or 7 miles below St. Cloud. Lines of glacial drainage from the gray drift carried gravel containing much limestone down to the Mississippi through areas of red drift in the southeast part of the county and spread it as far north as St. Joseph and St. Cloud. At that time there was eastward drainage along the north side of the Grantsburg lobe from the Mississippi to the St. Croix River.

The gray drift in northwestern Stearns County has an attenuated edge that extends several miles east of the first well defined moraine. This moraine follows Sauk River valley from Sauk Center to New Munich on the south side of the stream and then crosses to the north side and runs eastward to Cold Spring. There is another till plain on the southwest side of this moraine, extending to the great gravel plain formed along the outer edge of the strong morainic system in Pope County. The outer member of that morainic system comes into the southern part of Stearns County near Paynesville, and runs northeastward nearly to Cold Spring and then turns southward, and passes into Meeker County south of Kimball.

The red drift area, and the east part of the gray drift in this county were covered by forest, but the southwest part of the county was prairie except some brushy land on the gravel plain.

There are numerous small outcrops of granite in the eastern part of the county along the Mississippi and the Sauk River valleys, and also in the northwest part at Melrose and at Sauk Center. The largest area is in western St. Cloud Township, where it is at or near the surface over several square miles. The combined areas of outcrops in the county are estimated, however, to be not more than 10 square miles, and part of this has soil enough to be farm land.

The area of wet land is estimated by Ralph to be 62 square miles. This apparently includes the lakes as well as swamps and peat bogs. Some of the lakes are shallow enough to be drained by deep ditching.

The moraines of red drift are in places so rough and stony that they are still in forest. There is, however, a considerable part of the red drift with only a moderate number of bowlders and cobble stones. The red drift till plains are largely cleared and farmed. The gray drift area, both in moraines and till plains, is of high fertility, much of it being a pebbly clay loam. The outwash plains both of gray drift and red have a light soil but are extensively cultivated.

Percentages of Classes of Land in Stearns County

	Square miles	Per cent
Gravelly red drift moraine, sandy and stony loam	115	8.44
Clayey red drift moraine, pebbly clay loam	55	4.03
Red drift till plain, chiefly pebbly clay loam	120	8.81
Red drift outwash, sandy and stony loam	50	3.67
Gray drift moraine, chiefly pebbly clay loam	150	11.01
Gray drift till plain, chiefly pebbly clay loam	430	31.57
Gray drift outwash, sandy and stony loam	370	27.16
Swamps and peaty bogs	62	4.55
Rocky areas	10	0.74
	1,362	99.98

Farm and Crop Data for Stearns County from Census of 1910

Rural population 26,941 or 20 per square mile	
Per cent of land area in farms	87.3
Per cent of farm land improved	59.4
Average acres per farm	178.9
Average improved acres per farm	106.3
Value of all farm property	$34,548,484
Per cent of increase 1900 to 1910	85.4
Value of all crops in 1909	$5,384,327
Cereals (wheat, oats, corn, barley, rye)	$4,178,967
Other grains and seeds	$161,822
Hay and forage*	$617,326
Vegetables	$219,733
Fruits and nuts	$12,906
All other crops	$193,573

* Tame grass, 50,001 tons; wild grass, 106,587 tons.

BENTON COUNTY

Benton County is situated on the east side of Mississippi River in central Minnesota, with Foley as the county seat. The drainage tends to take courses parallel with the Mississippi rather than toward it. Consequently very little water enters the Mississippi in this county. The western part drains through Elk River southeastward across Sherburne County, while the southeast part drains southeastward into Rum River, which enters the Mississippi at Anoka.

A large part of the county is occupied by a red drift till plain. The only moraine is a narrow one in the northeast part. There are sandy plains of outwash gravels on the west and south borders, and narrow belts of dune sand associated with them. The till plain has partially filled interglacial valleys which were eroded in the old gray drift which underlies the red Wisconsin drift at moderate depths and outcrops in some of the bluffs. The red drift of this county though somewhat stony has usually sufficient clay admixture to make a good soil.

An esker, or sharp gravel ridge, several miles in length, runs from Ronnely southwestward, passing just south of Foley. It is of considerable value for railway and road ballast.

Granite outcrops are numerous in the western part of the county, where rock is struck at slight depth in a strip 2 to 3 miles wide and several miles long, extending from Sauk Rapids northward past Watab. There are also small outcrops in the northeast part of the county along West Rum River.

The wet lands of Benton County are estimated by Ralph to occupy 10,000 acres or 15.6 square miles. A considerable part of the wet land is in the sandy plain along the Mississippi. Some of it is in the line of the partially filled interglacial valleys.

The county was largely covered with hardwood forest, but in the sandy lands along the Mississippi valley and in the southern part of the county there was a light growth of scrub oak.

Percentages of Classes of Land in Benton County

	Square miles	Per cent
Moraine, red drift, chiefly pebbly clay loam soil	10	2.47
Red drift till plain, chiefly pebbly clay loam soil	288	71.11
Eskers and sharp gravelly knolls	2	0.50
Red drift outwash plains and sandy glacial drainage	70	17.28
Rock outcrops	20	4.94
Swamps	15	3.70
	405	100.00

Farm and Crop Data for Benton County from Census of 1910

Rural population 7,586 or 18.7 per square mile

Per cent of land in farms	75.3
Per cent of farm land improved	55.8
Average acres per farm	152.6
Average improved acres per farm	85.1
Value of all farm property	$8,389,346
Per cent of increase 1900 to 1910	115.6
Value of all crops in 1909	$1,176,027
Cereals (oats, wheat, corn, rye, barley)	$775,985
Other grains and seeds	$22,896
Hay and forage*	$209,651
Vegetables	$104,496
Fruits and nuts	$6,709
All other crops	$56,290

* Tame grass, 14,256 tons; wild grass, 34,221 tons.

SHERBURNE COUNTY

Sherburne County is situated east of the Mississippi River, in the south central part of Minnesota, with Elk River as the county seat. It has a land area of 448 square miles, to which should be added 15 to 20 square miles in lakes.

Elk River gathers nearly all the drainage of Sherburne County and parallels the Mississippi from the northwest to the southeast corner of the county, where it enters the Mississippi. The eastern part of the county drains into Rum River and thence to the Mississippi River at Anoka.

With the exception of the northern edge of the county, where there are a few square miles of clayey ground moraine of red drift, the Grantsburg lobe of the Keewatin ice field covered the entire county. Its morainic ridges and knolls have gray drift material with a large red drift admixture. The movement of the Keewatin ice was northeastward, and the drainage on its north side took a northeastward course along or near the ice border to the end of the lobe and thence down the St. Croix valley. Part of it was ponded, as indicated in the discussion of Mille Lacs and Kanabec counties, but there seems to have been a rather free current across northern Sherburne County which deposited sand and fine gravel rather than mud or silt.

Along the Mississippi and Elk rivers there is a long strip of gravelly outwash, with light sandy soil. To the east of this strip are large areas covered by fine dune sand, above which there rise a few sharp morainic knolls and ridges. There are gravel plains with light sandy soil also along St. Francis River in the north part of the county. A large area in the southeast part of the county comprises mainly moraines of sandy till with loamy soil.

The amount of wet land in Sherburne County is estimated to be 10,000 acres, and is largely in marshy bogs among sandy areas.

The variable character of the soil is set forth in the table below:

Percentages of Classes of Land in Sherburne County

	Square miles	Per cent
Sandy gray drift moraine; soil sandy and stony loam	42	9.38
Clayey gray drift; soil pebbly clay loam	15	3.34
Sandy gray drift till plain; soil sandy to stony loam	14	3.13
Clayey gray drift till plain; soil pebbly clay loam	6	1.34
Clayey red drift till plain; soil pebbly clay loam	12	2.68
Marshes and swamps	15	3.34
Outwash gravel and sand	180	40.18
Dune sand	164	36.60
	448	99.99

Farm and Crop Data for Sherburne County from Census of 1910

Rural population 5,591 or 12.5 per square mile.	
Per cent of land in farms	71.3
Per cent of farm land improved	54.2
Average acres per farm	171.9
Average improved acres per farm	93.2
Value of all farm property	$7,432,444
Per cent of increase 1900 to 1910	117.3
Value of all crops in 1909	$1,039,917
Cereals (corn, oats, rye, wheat, barley)	$558,392
Other grains and seeds	$9,500
Hay and forage*	$148,105
Vegetables	$289,746
Fruits and nuts	$2,417
All other crops	$31,757

* Tame grass, 12,281 tons; wild grass, 18,342 tons.

ISANTI COUNTY

Isanti County is located in the eastern part of Minnesota, with Cambridge as the county seat. The greater part of the county is drained southward through Rum River to the Mississippi, but the southeast part drains eastward to the St. Croix River.

This county, like Sherburne, is extensively covered by fine dune sand which has found lodgement on till areas and buried the till to a depth of many feet. Outside the dune sand area there are moraines and till plains and small outwash gravel plains, chiefly in the northern and eastern parts of the county. There is, however, a small morainic area in the southwest part.

The gray till of the Grantsburg lobe extends nearly to the northern limits of the county. Ponded waters outside the ice laid down lake clays in the northwest corner of the county. A few square miles along the north edge of the county have the red till at the surface. The gray drift shows considerable variation in character of soil, both in moraines and till plains, part being clayey and part loose-textured and sandy.

On the dune sand a large amount of truck gardening has been developed, and it has thus become fully as profitable as the till areas. The sand is so fine as to hold considerable capillary water which carries crops through seasons of drouth.

The wet lands of the county are estimated by Ralph to occupy 20,000 acres or 31 square miles. Some of the lakes may have been included in this estimate, as they are very shallow, and in places marshy. Levels of some of the lakes of the western part of the county once stood several feet higher than at present.

Percentages of Classes of Land in Isanti County

	Square miles	Per cent
Gray drift moraine, sandy or stony loam	40	9.05
Gray drift moraine, pebbly clay loam	35	7.92
Gray drift till plain, sandy to stony loam	35	7.92

Percentages of Classes of Land in Isanti County (Continued)

	Square miles	Per cent
Gray drift till plain, pebbly clay loam	50	11.31
Red drift till plain, pebbly clay loam	10	2.26
Outwash gravel and sand	14	3.17
Lake clays in glacially ponded waters	9	2.04
Fine dune sand	218	49.32
Marshes and swamps	31	7.01
	442	100.00

Farm and Crop Data for Isanti County from Census of 1910

Rural population 10,793 or 24.4 per square mile

Per cent of land in farms	84.0
Per cent of farm land improved	46.1
Average acres per farm	115.2
Average improved acres per farm	53.1
Value of all farm property	$9,123,309
Per cent of increase 1900 to 1910	110.6
Value of all crops in 1909	$1,366,587
Cereals (oats, wheat, corn, rye, barley)	$521,758
Other grains and seeds	$36,521
Hay and forage*	$207,647
Vegetables	$518,608
Fruits and nuts	$4,278
All other crops	$77,775

* Tame grass, 18,002 tons; wild grass, 27,695 tons.

ANOKA COUNTY

Anoka County is situated in eastern Minnesota on the east side of the Mississippi River, with Anoka as its county seat. Nearly all the county drains southward or southwestward into the Mississippi, mainly through Rum River. A few square miles in the northeast part drain northeastward to the St. Croix River.

This county is extensively covered by fine dune sand, and the sand areas include large wire grass marshes, the dunes having blocked up the drainage. Most of the dunes were probably formed in the closing part of the glacial epoch, but there are a few places in which they are still active and have blowouts.

The entire county falls within the limits of the Grantsburg lobe of the Keewatin ice field, and carries a sheet of young gray drift. This is exposed at the eastern edge of the dune area in a plain of clayey calcareous till in the southeast part of the county. In the northwest part of the county, morainic ridges of the gray drift rise prominently above the surrounding plains. There is a fine gravelly outwash immediately bordering these morainic ridges on the east and south as far out as Rum River. The dune sand sets in east of the outwash plain, and apparently covers the till plain. The fertility of the dune sand is much greater than that of the plains of coarser material, owing probably to its yielding water by capillary action in seasons of drouth. But, in a few places renewed dune action has made very sandy loose soil.

The wet land of the county is largely embraced in the wire grass marshes which are estimated by Ralph to cover about 17 per cent of the county. Outside the marshes the county is timbered largely with scrub oak.

Percentages of Classes of Land in Anoka County

	Square miles	Per cent
Gray drift moraine, sandy to stony loam	10	2.18
Gray drift moraine, pebbly clay loam	12	2.61
Gray drift till plain, sandy to stony loam	9	1.96
Gray drift till plain, pebbly clay loam	30	6.54
Outwash plains of sandy gravel	75	16.34
Marshes and swamps	78	17.00
Dune sand	245	53.37
	459	100.00

Farm and Crop Data for Anoka County from Census of 1910

Rural population 7,710 or 17 per square mile	
Per cent of land in farms	69.1
Per cent of farm land improved	50.0
Average acres per farm	140.6
Average improved acres per farm	70.3
Value of all farm property	$9,478,621
Per cent of increase 1900 to 1910	128.5
Value of all crops in 1909	$1,118,212
Cereals (corn, oats, rye, wheat, barley)	$393,435
Other grains and seeds	$9,383
Hay and forage*	$236,258
Vegetables	$406,395
Fruits and nuts	$12,597
All other crops	$60,144

* Tame grass, 16,552 tons; wild grass, 22,814 tons.

CHISAGO COUNTY

Chisago County is situated on the eastern border of the state with Center City as the county seat. It has a land area of 427 square miles, and lakes occupy an additional 30 square miles. The county all drains to the St. Croix River. The lakes which abound in the southern part of the county seem to be in the line of partly filled valleys.

The entire county, except a few square miles in the southeast corner, was covered by the Grantsburg lobe of the Keewatin ice field. The most extensive soil class is a pebbly clay loam in a broad plain of young gray till. Near the eastern edge of the county the gray till in places only veneers ridges and knolls of the red drift. There is a broad strip of dune sand in the western part of the county, extending east to Sunrise river and north as far as Harris.

There is a well defined moraine of the gray drift along the east side of Sunrise River, formed on the southeast side of the Grantsburg lobe, and also one in the extreme eastern part of the county. Moraines in the northwest part were formed on the northwest edge of the ice lobe. The dune sand covers a low plain along the axis of movement of the ice lobe.

On the dune sand area there were oak openings, but the heavier soil had a more dense forest, largely of oak.

Percentages of Classes of Land in Chisago County

	Square miles	Per cent
Gray drift moraine, chiefly pebbly clay loam	80	18.74
Gray drift moraine, sandy to stony loam	20	4.68
Gray drift till plain, sandy to stony loam	12	2.81
Gray drift till plain, pebbly clay loam	142	33.25
Dune sand	90	21.08
Valley alluvium, sandy	60	14.05
Swamp	23	5.38
	457	99.99

Farm and Crop Data for Chisago County from Census of 1910

Rural population 9,547 or 22.4 per square mile

Per cent of land in farms	82.6
Per cent of farm land improved	46.4
Average acres per farm	112.6
Average improved acres per farm	52.2
Value of all farm property	$12,289,044
Per cent of increase 1900 to 1910	108.1
Value of all crops in 1909	$1,544,517
Cereals (oats, wheat, corn, barley, rye)	$616,999
Other grains and seeds	$5,131
Hay and forage*	$412,579
Vegetables	$407,986
Fruits and nuts	$7,802
All other crops	$94,020

* Tame grass, 41,363 tons; wild grass, 20,020 tons.

WASHINGTON COUNTY

Washington County is located on the eastern border of the state with Stillwater as the county seat. Its land area is 397 square miles, and there is an additional 21 square miles in lakes. The greater part of the county drains into the St. Croix River, but a strip along the western edge drains more directly to the Mississippi. The valleys of both these rivers have been deeply channeled and terraced by lines of glacial drainage and larger rivers from the outlets of the glacial lakes Duluth and Agassiz, so that the streams are below the 700-foot contour, while the bordering uplands are 900 to 1,050 feet or more.

The Keewatin young gray drift extends a few miles into the northwest part of the county, northward from White Bear Lake. But in the remainder of the county the red drift is at the surface. The border of the young or Wisconsin red drift lies back a few miles northwest of the junction of the St. Croix and Mississippi rivers, leaving the older red drift exposed in a narrow strip on the west side of the St. Croix below the village of Afton. This older red drift has a more mature drainage development than the young red drift, and very few undrained depressions. The later drift is very thickly set with lakes and undrained depressions, and is very largely of morainic topography. The young gray drift forms only a veneer over the red drift, but is sufficiently thick to give it the characteristic pebbly clay loam soil. The red drift is largely a stony loam, though with a considerable admixture of clay.

The county was occupied very largely by oak forest sufficiently open to be classed as oak openings, and farming development started in this county very early.

Percentages of Classes of Land in Washington County

	Square miles	Per cent
Old red drift till plain chiefly pebbly clay loam	35	8.82
Red drift moraine chiefly pebbly clay loam	139	35.00
Red drift till plain chiefly pebbly clay loam	25	6.30
Red drift outwash and glacial drainage, sandy to stony loam	80	20.16
Gray drift moraine chiefly pebbly clay loam	28	7.05
Gray drift till plain chiefly pebbly clay loam	22	5.54
Gray drift outwash, sandy to stony loam	18	4.53
Dune sand	5	1.26
Valley alluvium, sandy and stony	30	7.56
Swamps and bogs	15	3.78
	397	100.00

Farm and Crop Data for Washington County from Census of 1910

Rural population 11,975 or 30 per square mile	
Per cent of land in farms	89.1
Per cent of farm land improved	67.5
Average acres per farm	116.5
Average improved acres per farm	78.6
Value of all farm property	$16,334,539
Per cent of increase 1900 to 1910	80.2
Value of all crops in 1909	$2,129,792
Cereals (oats, corn, barley, wheat, rye)	$1,291,178
Other grains and seeds	$16,422
Hay and forage*	$463,802
Vegetables	$245,008
Fruits and nuts	$39,261
All other crops	$74,121

* Tame grass, 47,696 tons; wild grass, 6,294 tons.

Orchard fruits are grown much more than in counties to the north. Vegetables are a less important crop than in the more sandy counties to the north and northwest. Hay is an important crop, and is more largely of cultivated grasses than in the counties remote from the cities of St. Paul and Minneapolis, as only the better classes of hay find good market in the cities.

RAMSEY COUNTY

Ramsey County, with St. Paul as its seat, is located in the southeastern part of the state, and is the smallest county in the state, its land area being only 161 square miles. There is an additional 13.45 square miles in the lakes and streams within or on the borders of the county.

The Mississippi River is at and near the southern edge of the county in a deep rock-bound valley along part of which broad rock shelves are exposed by erosion and the removal of drift deposits by glacial drainage which made the valley. A small preglacial valley which comes into the present Mississippi near the Union Depot at St. Paul is only partly filled with drift, and furnishes a line of entry for several of the railways coming into the city from the east and north.

There are a few square miles of gray drift in the southwest part of the county, but the remainder of the county is largely red drift moraine with outwash gravel plains among the morainic ridges. The moraines though filled with gravelly pockets usually have at surface a rather clayey till. The morainic ridges in the western part of the county have a thin veneer of gray till, and the drift knolls formed by the Keewatin ice include large masses of red till with the gray till.

The rural population is only 35 persons to the square mile, and the development of intensive farming is less than is usual on the outskirts of a large city. Ordinarily farming is carried on right up to the city limits, and crops of hay are relatively large.

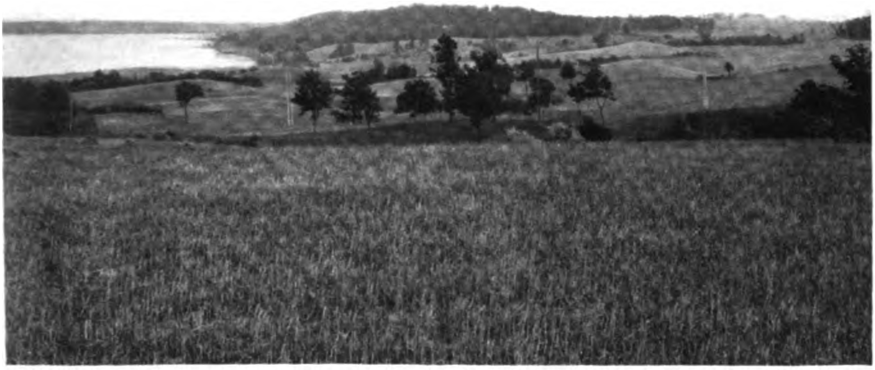
Percentages of Classes of Land in Ramsey County

	Square miles	Per cent
Red drift moraine, chiefly pebbly clay loam	36	22.36
Red drift outwash, gravelly loam	15	9.31
Gray drift moraine, chiefly pebbly clay loam	48	29.81
Gray drift outwash, sandy to gravelly loam	15	9.31
Dune sand	18	11.18
Swamp and bogs	14	8.70
Valley alluvium, sandy	5	3.11
Rock terraces and rocky valley beds	10	6.22
	161	100.00

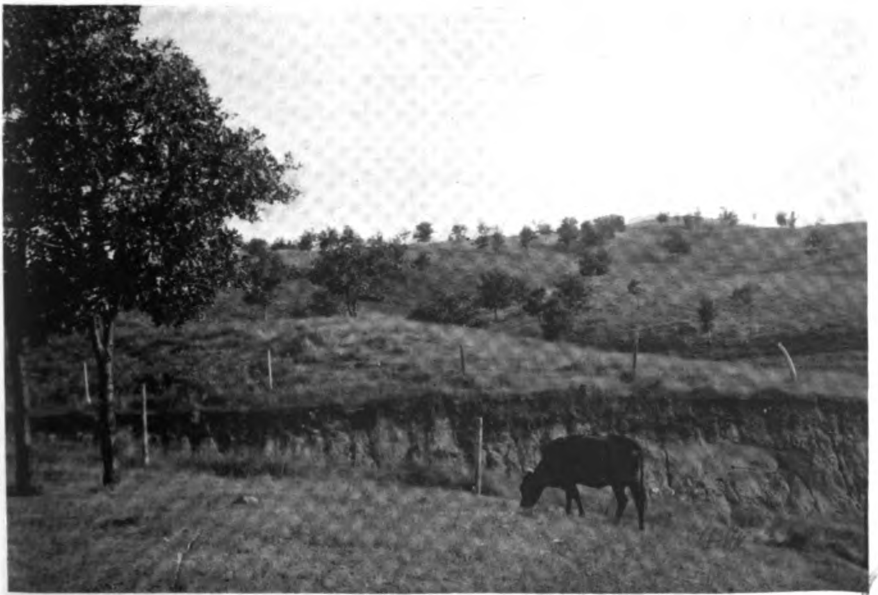
Farm and Crop Data for Ramsey County from Census of 1910

Rural population 5,647 or 35 per square mile	
Per cent of land in farms	58.8
Per cent of farm land improved	68.0
Average acres per farm	56.7
Average improved acres per farm	38.6
Value of all farm property	$9,726,904
Per cent of increase 1900 to 1910	74.8
Value of all crops in 1909	$1,072,780
Cereals (oats, corn, barley, wheat, rye)	$197,577
Other grains and seeds	$2,323
Hay and forage*	$254,970
Vegetables	$383,896
Fruits and nuts	$23,825
All other crops	$210,189

* Tame grass, 16,175 tons; wild grass, 5,552 tons.



A. GRAY DRIFT MORAINE NORTH OF ST. PAUL



B. RED DRIFT MORAINE WITH COATING OF GRAY DRIFT NORTH OF ST. PAUL

UNIV. OF MICH.

HENNEPIN COUNTY

Hennepin County, of which Minneapolis is the county seat, has a land area of 565 square miles, and a water area in lakes and streams of an additional 70 square miles. The drainage is largely eastward or northeastward into the Mississippi, there being only a few small creeks flowing to the Minnesota River, which forms part of the southern boundary of the county. Minneapolis has, in the Falls of St. Anthony on the Mississippi, a very valuable water power, which has greatly added to the profits of the farming communities of southern Minnesota by giving milling advantages near home and an excellent market for grain. The Falls of Minnehaha, and much of the picturesque gorge of the Mississippi below the falls of St. Anthony are within the limits of Hennepin County, as is also the beautiful Lake Minnetonka and numerous smaller lakes with attractive scenic features.

With the exception of less than a square mile near Prospect Park, in the east part of Minneapolis, the entire county was covered by the Keewatin ice sheet. In the east part of the county, however, a prominent red drift moraine was overridden by the Keewatin ice and nearly all veneered with the young gray drift. Many of the red gravel plains and ridges were greatly disturbed by the encroachment of the Keewatin ice, and the red drift was thus gathered up and locally incorporated with the gray. From Lake Minnetonka to the north, south, and west, the Keewatin drift is so thick that exposures of the red drift are rare. Outwash plains of gray drift gravel and sand are extensive in the district south of Minneapolis between the Mississippi and Minnesota valleys. They are also notable within the city and northward along the Mississippi valley. These level outwash areas are largely devoted to truck gardening. The rich black loam is highly fertilized and is very productive. The moraines, on the border of Lake Minnetonka, are largely in orchards and vineyards, but elsewhere are commonly given over to general farming.

The occurrence of numerous bogs and marshy depressions among the knolls and ridges causes much waste land, while the hills and ridges themselves are too steep for easy cultivation. The percentage of improved land is therefore low, except on the sandy outwash plains, and many hillside slopes are still in forest. The presence of the forests adds greatly to the beauty of suburban homes and this perhaps more than offsets the agricultural disadvantages. Such suburban occupancy will naturally spread widely over the morainic areas west of Minneapolis, and especially around Lake Minnetonka with its numerous bays and arms.

According to the census of 1910, the area planted to potatoes in 1909 amounted to 27 square miles, and about 6 square miles to other vegetables. The gross income from vegetable raising averaged $36,500.00 per square mile, or about $57.00 per acre. Large areas near Minneapolis are well adapted to truck gardening, and will naturally be utilized thus in the near future.

Percentages of Classes of Land in Hennepin County

	Square miles	Per cent
Gray drift moraine (partly over red drift moraine) soil pebbly clay loam...	195	34.49
Gray drift till plain, pebbly clay loam	111	19.65
Gray drift outwash and glacial drainage, sandy gravel	116	20.53
Dune sand	4	0.71
Valley alluvium, largely sandy	35	6.19
Rock areas	2	0.35
Marshes and bogs	102	18.06
	565	100.00

Farm and Crop Data for Hennepin County from Census of 1910

Rural population 18,806 or 37.6 per square mile*

Per cent of land in farms	78.6
Per cent of farm land improved	66.7
Average acres per farm	73.8
Average improved acres per farm	49.2
Value of all farm property	$34,967,221
Per cent of increase 1900 to 1910	75.6
Value of all crops in 1909	$4,132,598
Cereals (corn, oats, wheat, barley, rye)	$1,341,442
Other grains and seeds	$10,398
Hay and forage†	$833,914
Vegetables	$1,237,191
Fruits and nuts	$220,574
All other crops	$489,079

* Deducting city area there remains about 500 square miles in farms.

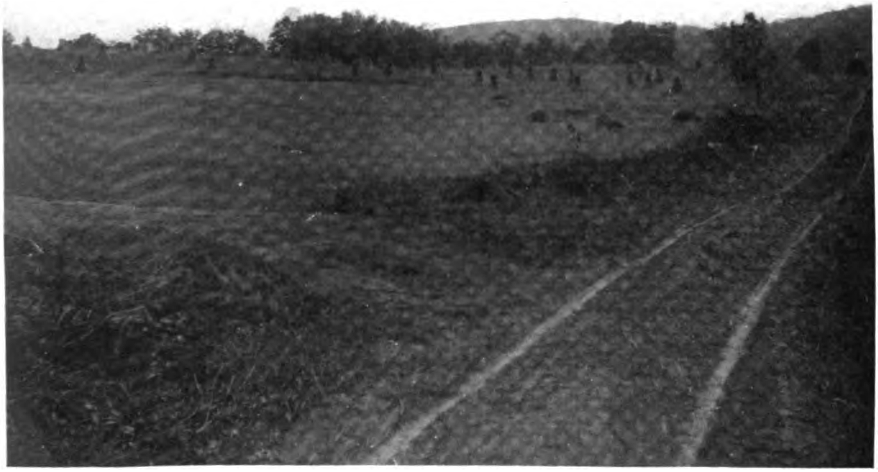
† Tame grass, 61,186 tons; wild grass, 45,521 tons.

WRIGHT COUNTY

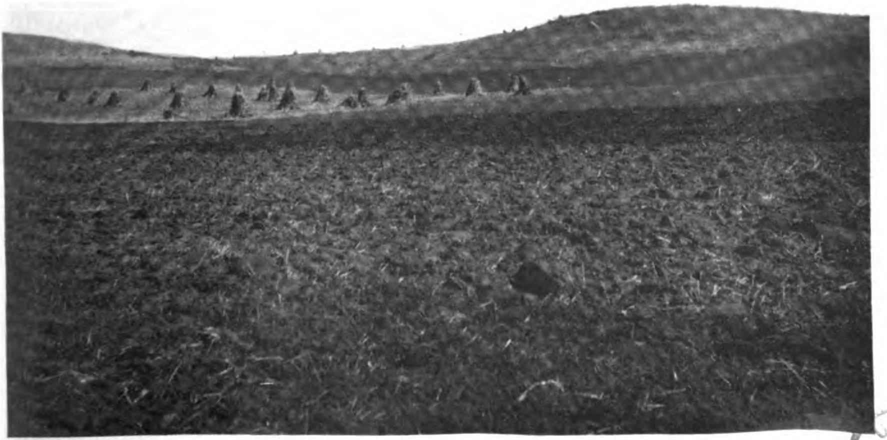
Wright County is situated in the south central part of Minnesota with Buffalo as the county seat. Most of the county is drained to the Mississippi by Crow River, which enters it and also forms part of its eastern boundary. Small lakes are scattered all over the county, and occupy about 23 square miles of its area of 714 square miles.

Wright County is crossed by several moraines formed by the Grantsburg lobe of the Keewatin ice field. The ice stood on the Crow valley, while the glacial drainage discharged from the moraines on the northeast side of the lobe to the Mississippi. Outwash aprons, or plains of sandy gravel are thus extensive in the northern part of the county. Smaller ones lie along Crow River valley, which subsequently carried an important line of glacial drainage into the Mississippi. The outwash plains are covered to some extent with a loam which increases their fertility.

Although this county was covered with heavy hardwood forest, it has nearly all been converted into farm land, there being 90.3 per cent of the county in farms. Of this, however, only about 60 per cent is im-



A. **WISCONSIN, OR YOUNG RED DRIFT, MORAINE NEAR STILLWATER**



B. OLD RED DRIFT MORAINE NEAR HAMPTON

UNIV. OF MICH.

proved. Part of the unimproved land is in swamps, but nearly every farm has a few acres of wood-lot. The moraines, though having many small knolls, and a somewhat varied soil, ranging from clayey to gravelly, are developed agriculturally nearly as much as the relatively smooth till plains with prevailing clay loam soil.

Percentages of Classes of Land in Wright County

	Square miles	Per cent
Gray drift moraine with clayey to mixed soil	186	26.91
Gray drift till plain, chiefly pebbly clay loam	230	33.28
Outwash plains of sandy gravel and sandy loam soil	140	20.26
Swamps and bogs	135	19.52
	691	99.97

Farm and Crop Data for Wright County from Census of 1910

Rural population 20,064 or 29 per square mile	
Per cent of land area in farms	90.3
Per cent of farm land improved	59.5
Average acres per farm	104.7
Average improved acres per farm	62.3
Value of all farm property	$27,922,225
Per cent of increase 1900 to 1910	97.9
Value of all crops in 1909	$3,477,587
Cereals (wheat, corn, oats, barley, rye)	$2,586,307
Other grains and seeds	$13,147
Hay and forage*	$456,393
Vegetables	$208,349
Fruits and nuts	$38,097
All other crops	$175,294

* Tame grass, 53,698 tons; wild grass, 52,017 tons.

MEEKER COUNTY

Meeker County is located in the south central part of Minnesota, with Litchfield as the county seat. The drainage is almost entirely eastward by the two forks of Crow River to the Mississippi. A small area near Eden Valley, however, drains northward to Sauk River, and thence northeast to the Mississippi. At one time in the course of the melting of the Keewatin ice field, this northward line carried the drainage of a large part of the county, for the Crow River valley to the east of Meeker County was still covered by the ice. A lake several miles in width then occupied the low land bordering Crow River valley between Manannah and Kingston, and discharged northward across a broad marshy valley past the site of the village of Eden Valley. This lake deposited a calcareous silt and fine sand brought into it by glacial waters from the east and south. At the south edge of the lake, an extensive outwash gravel plain, on which the villages of Litchfield and Darwin stand, was built by the waters escaping northward from the ice. This lake area and the bordering outwash and till plain lie between two large moraines which unite a few miles west in Kandiyohi County to form the great morainic system developed on the east side of the Keewatin ice field.

The northern and earlier of the two moraines just mentioned touches the northwest and also the northeast corner of Meeker County but lies mainly in Stearns County. The southern moraine crosses the southern part of the county, and bears northeastward into Wright County. There is an extensive till plain on the southern or inner border of this moraine, extending from southwestern Meeker County into neighboring counties on the south and west.

The moraines as well as till plains are very largely of clay loam. There are, however, gravelly knolls and ridges along the outer edge of each moraine next to the outwash plains. The sediments of the glacial lake above noted are of fine sand on the edge, but are a rich silt loam in the deeper part between Forest City and Kingston. The outwash plains, though underlain by gravel, have in places a loamy soil and subsoil 2 to 4 feet deep which render them the more productive. A considerable part, however, has a light sandy soil.

Meeker County stands on the border between prairie and hardwood forest. There were groves on the prairie parts and strips of prairie extended back for some miles into the forest. The forest was of oak openings on the sandy soil, but heavier with mixed hardwood on the clay soils.

Percentages of Classes of Land in Meeker County

	Square miles	Per cent
Gray drift moraine, chiefly pebbly clay loam	190	30.59
Gray drift till plain, chiefly pebbly clay loam	260	41.87
Outwash sand and gravel plains, sandy to loamy	70	11.27
Lacustrine deposits with silt loam soil	30	4.83
Lacustrine deposits with sandy soil	40	6.44
Marshes and swamps	31	5.00
	621	100.00

Farm and Crop Data for Meeker County from Census of 1910

Rural population 12,826 or 20.6 per square mile

Per cent of land area in farms	90.2
Per cent of farm land improved	75.5
Average acres per farm	152.8
Average improved acres per farm	115.3
Value of all farm property	$21,595,297
Per cent of increase 1900 to 1910	82.4
Value of all crops in 1909	$3,310,451
Cereals (wheat, oats, corn, barley, rye)	$2,731,476
Other grains and seeds	$76,401
Hay and forage*	$351,107
Vegetables	$68,656
Fruits and nuts	$19,531
All other crops	$63,280

* Tame grass, 34,223 tons; wild grass, 58,252 tons.

A. OUTWASH PLAIN EAST OF ANOKA. DUNE SAND ON RIGHT CUT BY RAILROAD

B. OUTWASH PLAIN OF GRAY DRIFT WEST OF WHITE BEAR

C. OUTWASH PLAIN WITH THICK CLAYEY COVERING NEAR GARVAIS AND VADNIS LAKES, NORTH OF ST. PAUL

UNIV. OF MICH.

KANDIYOHI COUNTY

Kandiyohi County, of which Willmar is the county seat, has a land area of 801 square miles, and an estimated additional lake area of 53 square miles. The lakes are especially numerous in a belt running from northwest to southeast across the county. The drainage of the northeast part is eastward by Crow River to the Mississippi, and of the southwest part is southwestward to the Minnesota River.

The great morainic system formed on the east side of the Keewatin ice sheet comes into the county from the northwest and is combined into a single broad morainic belt as far as Green Lake. It there forks, and the northern or outer member leads northeastward into Stearns County, while the southern member continues southeastward into Meeker County. There is also a weak moraine leading from Green Lake to Atwater, which is separated from the large moraine south of it by a space of about 2 miles of till plain. South of this great morainic system is a till plain extending into Renville County, the only interruption being a narrow moraine less than a mile wide that runs eastward through the southwest township of the county south of Prinsburg. There are also a few sharp gravelly knolls east of Raymond. Another till plain lies between the two members of the great morainic system east of Green Lake. This is traversed by sandy strips marking lines of glacial drainage to the middle fork of Crow River. The north part of the county is occupied by a great gravel outwash plain that extends into Pope and Stearns counties.

There is gravelly and loose-textured drift along the border of the great morainic system next to the gravel plain, but within 2 or 3 miles back the moraine becomes more clayey, though there are gravelly knolls here and there over it. The till plain has a rich black clay loam soil, such as covers the great plain along the Minnesota valley. Some of the marshes and peaty bogs may be easily drained, but others seem to be down to the level of the underground water table. The marshes and bogs are quite extensive in the gravel plain, and are in some cases 20 to 40 feet below the general level of the plains. The aggregate amount of wet land is probably as great as the area of the lakes, or not less than 63 square miles.

Percentages of Classes of Land in Kandiyohi County

	Square miles	Per cent
Gray drift moraine with gravelly or stony loam	100	12.48
Gray drift moraine with pebbly clay loam	180	22.47
Gray drift till plain, chiefly pebbly clay loam soil	378	47.19
Gray drift outwash, sandy and gravelly loam	80	10.00
Marshes and bogs	63	7.86
	801	100.00

Farm and Crop Data for Kandiyoki County from Census of 1910

Rural population 12,880 or 16 per square mile

Per cent of land area in farms	**90.4**
Per cent of farm land improved	**79.8**
Average acres per farm	**207.1**
Average improved acres per farm	**165.2**
Value of all farm property	**$22,711,957**
Per cent of increase 1900 to 1910	**93.9**
Value of all crops in 1909	**$3,410,101**
Cereals (wheat, oats, barley, corn, rye)	**$2,755,099**
Other grains and seeds	**$133,508**
Hay and forage*	**$401,612**
Vegetables, fruits, and nuts	**$62,660**
All other crops	**$17,492**

*** Tame grass, 29,094 tons; wild grass, 80,684 tons.**

SWIFT COUNTY

Swift County is located in southwestern Minnesota with Benson as the county seat. The drainage is all southward or southwestward through the Pomme de Terre and Chippewa rivers to the Minnesota.

Part of the strong morainic system that was formed along the east side of the Keewatin ice field crosses the northeast corner of the county and occupies about 120 square miles. The remainder of the county is largely till plain, but small till ridges occur here and there in the southern part, and narrow moraines with strips of outwash between them cross the southwest corner of the county. A larger morainic belt traverses the northwest part of the county, and east of this is an extensive sandy outwash plain.

Some marshy land occurs in depressions in the sandy plain northwest of Benson, and there are small areas of wet land on the till plain and a few bogs in the large moraine. But the aggregate area of wet land scarcely reaches 20 square miles. The greater part of the county has a rich black clay loam soil such as characterizes the great till plain along the Minnesota valley.

Percentages of Classes of Land in Swift County

	Square miles	Per cent
Gray drift moraine, chiefly pebbly clay loam	200	27.00
Gray drift till plain, chiefly pebbly clay loam	340	45.88
Outwash plains of sand and sandy loam	181	24.42
Marshes and swamps	20	2.70
	741	100.00

Farm and Crop Data for Swift County from Census of 1910

Rural population 7,533 or 10.2 per square mile

Per cent of land area in farms	86.2
Per cent of farm land improved	88.6
Average acres per farm	265.9
Average improved acres per farm	235.6
Value of all farm property	$18,206,728
Per cent of increase 1900 to 1910	92.4

Farm and Crop Data for Swift County (Continued)

Value of all crops in 1909	$3,097,049
Cereals (wheat, oats, corn, barley, rye)	$2,701,830
Other grains and seeds	$103,850
Hay and forage*	$226,318
Vegetables	$54,332
Fruits and nuts	$4,556
All other crops	$6,161

* Tame grass, 19,013 tons; wild grass, 36,177 tons.

CHIPPEWA COUNTY

Chippewa County is located on the north side of the Minnesota River in the southwest part of the state, with Montevideo as the county seat. The drainage is all southward or southwestward to the Minnesota River. The Minnesota valley was excavated by the river from the glacial Lake Agassiz to a depth of more than 100 feet, and has several channels in the part above the mouth of the Chippewa River with island-like remnants of the upland between them. The river cut the valley down to the granite in the vicinity of Montevideo and Granite Falls.

The county is nearly all a smooth till plain with black prairie soil and pebbly clay loam subsoil. There are several narrow and interrupted morainic ridges traversing the county in a course parallel with the Minnesota, and these are in some cases bordered on the northeast by narrow strips of sandy outwash. The ridges are usually of clayey till with pebbly clay loam soil. A large part of the Minnesota valley has a stony to sandy loam soil. There is also some wet land in the valley, and perhaps two square miles of bare rock area.

Percentages of Classes of Land in Chippewa County

	Square miles	Per cent
Moraines and till ridges, pebbly clay loam	80	13.52
Till plains with black clay loam soil	414	70.05
Sandy and gravelly outwash	20	3.38
Stony loam and sand in Minnesota valley	50	8.46
Swamps and marshes chiefly in valley	25	4.24
Rock areas	2	0.34
	591	99.99

Farm and Crop Data for Chippewa County from Census of 1910

Rural population 8,434 or 14 per square mile	
Per cent of land area in farms	90.3
Per cent of farm land improved	87.8
Average acres per farm	228.0
Average improved acres per farm	200.0
Value of all farm property	$17,378,350
Per cent of increase 1900 to 1910	92.3
Value of all crops in 1909	$2,797,308
Cereals (oats, wheat, corn, barley, rye)	$2,439,238
Other grains and seeds	$53,986
Hay and forage*	$234,114
Vegetables	$47,277
Fruits and nuts	$6,762
All other crops	$15,931

* Tame grass, 20,679 tons; wild grass, 38,909 tons.

LAC QUI PARLE COUNTY

Lac qui Parle County is situated south of the Minnesota River on the western border of the state, with Madison as the county seat. The drainage is entirely northeastward into the Minnesota River, mainly through Yellow Bank and Lac qui Parle rivers.

Most of the county is a till plain with an altitude 1,000 to 1,200 feet, but the southwest corner is on the slope of the Coteau des Prairies and reaches an altitude of 1,400 feet. The Minnesota valley is cut to a depth of about 100 feet below the bordering till plain, and as in Chippewa County there are island-like strips of the till plain surrounded by channels cut by the outlet of Lake Agassiz which made the valley of the Minnesota. The village of Louisburg stands on the largest of these island strips. The Minnesota bottoms has exposures of bare granite amounting to perhaps 5 square miles within the county limits. Much of the bottom land is stony and too wet for cultivation.

The till plain has generally a black pebbly clay loam soil. There are several narrow moraines crossing it in the southwest part of the county, and strips of gently undulating land nearer the Minnesota which seem to mark later positions of the ice border. There are chains of gravel knolls in the western part of the county, and scattered gravel knolls in the southeast part. Outwash plains of sand and gravel border some of the weak morainic ridges in the southwest part of the county, but they comprise less than 5 per cent of the area.

Percentages of Classes of Land in Lac qui Parle County

	Square miles	Per cent
Gravelly gray drift moraines, pebbly clay loam	50	6.33
Clayey gray drift moraine, pebbly clay loam	160	20.25
Till plains, black pebbly clay loam	480	60.76
Outwash plains with sand or sandy loam soil	35	4.43
Rock ledges in Minnesota valley	5	0.63
Sandy and stony land in Minnesota valley	35	4.43
Marshy land, chiefly in Minnesota valley	25	3.16
	790	99.99

Farm and Crop Data for Lac qui Parle County from Census of 1910

Rural population 10,819 or 13.7 per square mile	
Per cent of land area in farms	91.8
Per cent of farm land improved	86.9
Average acres per farm	249.1
Average improved acres per farm	216.4
Value of all farm property	$26,217,879
Per cent of increase 1900 to 1910	104.4
Value of all crops in 1909	$4,150,755
Cereals (wheat, oats, corn, barley, rye)	$3,583,249
Other grains and seeds	$200,372
Hay and forage*	$278,300
Vegetables	$66,569
Fruits and nuts	$10,276
All other crops	$11,989

* Tame grass, 32,159 tons; wild grass, 36,957 tons.

YELLOW MEDICINE COUNTY

Yellow Medicine County is south of the Minnesota River and extends west to the state line along the south side of Lac qui Parle County. The county seat, Granite Falls, is at the eastern end and takes its name from falls in the Minnesota River at that point. The drainage is all northeastward into the Minnesota chiefly through Lac qui Parle and Yellow Medicine rivers.

The greater part of the county is a till plain standing between 1,000 and 1,200 feet, but the southwest part is on the eastern slope of the Coteau des Prairies and rises near the corner of the county to over 1,700 feet. There are several moraines traversing the county in a northwest to southeast course, but with the exception of a bulky one in the southwest corner they are all slender, with a width of 1 to 2 miles or even less.

Along the outer or southwest border of the moraines are channels that were formed by the glacial border drainage. These are now in part abandoned and hold marshes and bogs. Some of them, however, are utilized for considerable distances by the present drainage lines. The courses of the streams are subject to great diversion in some cases to find a passage through a morainic ridge.

The moraines contain a few gravel knolls, but are otherwise of a clayey till with pebbly clay loam soil. The lines of border drainage above noted usually have a silty or sandy loam soil. The till plains which occupy a large part of the county have a black prairie soil of slightly pebbly clay loam. The Minnesota valley has in places exposed granite hills, but much of the bottom land is sandy to stony loam with bowldery strips.

Percentages of Classes of Land in Yellow Medicine County

	Square miles	Per cent
Gray drift moraines, chiefly pebbly clay loam soil	235	31.38
Gray drift till plains, chiefly pebbly clay loam soil	439	58.61
Border drainage channels with sandy loam and peaty soil	50	6.67
Sandy and stony land in Minnesota valley	20	2.67
Rock areas in Minnesota valley	5	0.67
	749	100.00

Farm and Crop Data for Yellow Medicine County from Census of 1910

Rural population 10,825 or 14.5 per square mile

Per cent of land area in farms	94.2
Per cent of farm land improved	83.9
Average acres per farm	245.8
Average improved acres per farm	206.3
Value of all farm property	$24,607,037
Per cent of increase 1900 to 1910	103.9
Value of all crops in 1909	$3,525,571
Cereals (wheat, oats, corn, barley, rye)	$2,980,978
Other grains and seeds	$185,428
Hay and forage*	$272,573
Vegetables	$61,731
Fruits and nuts	$10,663
All other crops	$14,198

* Tame grass, 28,018 tons; wild grass, 42,314 tons.

RENVILLE COUNTY

Renville County is situated on the north side of the Minnesota River in the southwest part of the state, with Olivia as the county seat. The greater part of the county is drained southward to the Minnesota River, but the northeastern part is drained northeastward by Crow River to the Mississippi. The county has so few natural drainage lines that extensive ditching has been found necessary to carry off the surplus water.

This county is a great prairie till plain, with only a few narrow drift ridges or weak moraines that are more or less interrupted. The soil is a rich black clay loam. In a few places it is thickly strewn with bowlders. Gravel knolls, which are of high value for road ballast, are scattered widely over the plain and strewn along the lines of the moraines. The plain stands mainly between 1,000 and 1,100 feet above sea level, though its highest points are slightly above 1,100 feet. On this upland plain, wet lands can largely be drained and rendered tillable at moderate expense. The Minnesota River falls 50 feet or from 850 feet above sea level to 800 feet in its course along the border of the county. Its valley has numerous outcrops of granite rock, which in places rise to a height of 100 feet or more above the stream, or to within about 50 feet of the level of the bordering uplands. Parts of the bottom lands are wet and parts are sandy and stony.

Percentages of Classes of Land in Renville County

	Square miles	Per cent
Gravelly knolls in moraines and till plains, stony loam	20	2.05
Gray drift ridges, pebbly clay loam	110	11.25
Gray drift till plain, black clay loam	648	65.23
Plains with sand and sandy loam	12	1.23
Rock outcrops in Minnesota valley	13	1.33
Sandy and stony land in Minnesota valley	15	1.53
Wet land in Minnesota valley	10	1.03
Upland marshes and wet lands	150	15.33
	978	99.98

Farm and Crop Data for Renville County from Census of 1910

Rural population 15,794 or 16 per square mile

Per cent of land area in farms	94.2
Per cent of farm land improved	87.1
Average acres per farm	205.4
Average improved acres per farm	178.9
Value of all farm property	$33,685,584
Per cent of increase 1900 to 1910	81.7
Value of all crops in 1909	$5,370,879
Cereals (wheat, oats, corn, barley, rye)	$4,780,876
Other grains and seeds	$118,823
Hay and forage*	$349,488
Vegetables	$79,756
Fruits and nuts	$16,685
All other crops	$25,071

* Tame grass, 33,400 tons; wild grass, 87,880 tons.

MCLEOD COUNTY

McLeod County is situated about midway of the state in the fourth row of counties from the south, with Glencoe as the county seat. The drainage is nearly all northeastward to the Mississippi through Crow River, but the southern end drains eastward to the Minnesota.

The county is nearly all a very fertile till plain, and most of it stands between 1,000 and 1,100 feet above the sea, there being remarkably little range in altitude. The northwest corner is strongly morainic as it embraces the southern end of a spur from the great morainic system formed on the east side of the Keewatin ice field. This spur is at the place where the Grantsburg lobe branches off from the main or Des Moines lobe. Gravel knolls are scattered over the county in such a manner as to be accessible for road ballast in nearly every township, but the plains have black clayey loam with but few pebbles or bowlders.

Marshes and peat bogs are inclosed among the morainic knolls of the northwest part of the county and also fringe some of the lakes. A narrow strip of sandy gravel follows down the south fork of Crow River, which may have been a line of glacial drainage; but aside from this no outwash plains or sandy glacial drainage lines were noted.

Percentages of Classes of Land in McLeod County

	Square miles	Per cent
Gray drift moraine, chiefly pebbly clay loam	60	12.09
Gray drift till plain, black pebbly clay loam	370	74.60
Gravelly knolls and ridges, stony loam	25	5.04
Glacial gravel plains along Crow River, stony loam	15	3.02
Marshes and bogs	26	5.24
	496	99.99

Farm and Crop Data for McLeod County from Census of 1910

Rural population 12,278 or 25 per square mile	
Per cent of land area in farms	94.2
Per cent of farm land improved	80.3
Average acres per farm	131.8
Average improved acres per farm	105.8
Value of all farm property	$23,120,367
Per cent of increase 1900 to 1910	85.3
Value of all crops in 1909	$2,894,083
Cereals (wheat, corn, oats, barley, rye)	$2,382,431
Other grains and seeds	$33,951
Hay and forage*	$329,146
Vegetables	$67,102
Fruits and nuts	$13,787
All other crops	$67,666

* Tame grass, 33,458 tons; wild grass, 51,192 tons.

SIBLEY COUNTY

Sibley County lies west of the north flowing portion of Minnesota River, with Gaylord as its county seat. The drainage is nearly all eastward to the Minnesota. A narrow strip on part of the north border is drained northeastward by Crow River to the Mississippi. The altitude of the county, outside the Minnesota valley, is remarkably uniform, there being scarcely 100 feet variation. The northwest part stands about 1,050 to 1,075 feet, and there is a gradual descent to the southeast part, which is about 975 feet. The Minnesota valley is nearly 250 feet deep, the river being 717 feet at the south line of the county and just below 700 feet where it leaves the county. There are, however, terraces of glacial gravel along it 100 to 125 feet above the stream.

More than 90 per cent of the county, outside the river valley, is a smooth till plain, which was largely prairie, and has a rich black clay loam soil. There are weak morainic ridges in the southwest corner of the county, and occasional low knolls scattered widely over the county. The knolls and the morainic ridges contain a small amount of gravel, of great value for road ballast. The bottom lands and terraces of the Minnesota valley are generally sandy. There is a small amount of wet land lying below the level of the highest flood stages of the river. This land is rich and can be farmed except in years of exceptional floods.

Percentages of Classes of Land in Sibley County

	Square miles	Per cent
Moraines and scattered drift knolls, chiefly pebbly clay loam	30	5.11
Till plain, black pebbly clay loam	470	80.40
Upland swamps and wet land, largely capable of drainage, black clay loam	60	10.22
Sandy bottoms and terraces of Minnesota valley	10	1.71
Wet bottoms of Minnesota valley	15	2.56
	585	100.00

Farm and Crop Data for Sibley County from Census of 1910

Rural population 11,351 or 19.4 per square mile	
Per cent of land area in farms	95.4
Per cent of farm land improved	79.5
Average acres per farm	173.9
Average improved acres per farm	138.2
Value of all farm property	$22,006,868
Per cent of increase 1900 to 1910	67.4
Value of all crops in 1909	$3,117,610
Cereals (wheat, corn, oats, barley, rye)	$2,678,817
Other grains and seeds	$23,384
Hay and forage*	$291,130
Vegetables	$60,302
Fruits and nuts	$12,472
All other crops	$51,505

* Tame grass, 22,525 tons; wild grass, 67,183 tons.

CARVER COUNTY

Carver County is situated on the west side of the north flowing part of Minnesota River immediately southwest of Hennepin County, and Chaska is the county seat. The southeastern part of the county drains into the Minnesota River, but the northwest part is drained to the Mississippi River, chiefly by Crow River.

This county is largely occupied by the great morainic system formed on the east side of the Keewatin ice field, and has a knolly surface inclosing numerous small lakes and peat bogs. The western end of the county is a till plain, a continuation of the great plain bordering the Minnesota valley. There are also small till plains inclosed among the morainic ridges. Outwash plains open into the Minnesota valley, and the discharge of glacial waters was thence northeastward to the Mississippi.

The forests and lakes give a pleasing scenic effect and attractive setting for suburban residences. The county is traversed by several railroad lines leading direct to Minneapolis, and thus is likely to have in the near future a considerable suburban population. It is also favorably situated for quick marketing of produce, and much loose textured soil suitable for gardening. Thus far, however, it has been chiefly a grain and hay producing county. The till plain in the southwest part of the county has a rich black clay loam soil with pebbly clay loam subsoil.

Percentages of Classes of Land in Carver County

	Square miles	Per cent
Gray drift moraines, pebbly clay loam to gravelly loam soil	140	37.23
Outwash plains of sandy and gravelly loam	11	2.93
Till plains, chiefly of pebbly clay loam	180	47.87
Marshes and bogs on uplands	20	5.32
Sandy bottoms and terraces of Minnesota valley	15	3.99
Wet bottoms of Minnesota valley	10	2.66
	376	100.00

Farm and Crop Data for Carver County from Census of 1910

Rural population 11,247 or 30 per square mile

Per cent of land area in farms	89.9
Per cent of farm land improved	59.4
Average acres per farm	108.6
Average improved acres per farm	64.5
Value of all farm property	$20,370,744
Per cent of increase 1900 to 1910	118.0
Value of all crops in 1909	$2,264,655
Cereals (wheat, corn, oats, barley, rye)	$1,571,048
Other grains and seeds	$1,717
Hay and forage*	$400,851
Vegetables	$88,846
Fruits and nuts	$39,518
All other crops	$162,675

* Tame grass, 46,934 tons; wild grass, 29,890 tons.

SCOTT COUNTY

Scott County is situated on the east side of Minnesota River with Shakopee as the county seat. The drainage is northwestward to the Minnesota River, except a few square miles in the southeast part which drain eastward through Vermilion River to the Mississippi. The Minnesota valley is over 200 feet in depth, the river being below 700 and the bluffs over 900 feet. There are only a few square miles of the county standing above 1,100 feet.

The greater part of the county is strongly morainic, and is in the great morainic system formed on the east side of the Keewatin ice field. A till plain on the inner border of this morainic system occupies the southwest part of the county. Red drift is intermixed with the gray drift in notable amount in the east part of the county, and is found in outcrops and valley slopes beneath the gray drift clear to the western end of the county. The greater part of the drift, both in the moraines and till plains, is a clayey calcareous till with pebbly clay loam soil. There are, however, occasional knolls of gravel, and inclusions of gravel in the till which furnish suitable material for road ballast.

The Minnesota valley has broad terraces of sandy gravel at various heights up to more than 100 feet above the stream. On a low terrace west of Savage, the soil is in places light dune or sand but from Shakopee prairie up to Belle Plaine prairie there is usually a loamy rich soil. Rock ledges are exposed, or covered very thinly with loam and gravel, over an area of several square miles in the vicinity of Shakopee and Merriam. Low bottoms, subject in part to overflow, occupy about one fourth of the area of the valley in this county.

Percentages of Classes of Land in Scott County

	Square miles	Per cent
Gray drift moraine, chiefly pebbly clay loam	180	49.18
Gray drift till plain, black clay loam	72	19.66
Glacial drainage deposits of gravel and sand, terraces on Minnesota River	60	16.39
Low alluvial tracts along the Minnesota River	20	5.47
Marshes and bogs on uplands	34	9.29
	366	99.99

Farm and Crop Data for Scott County from Census of 1910

Rural population 9,885 or 27 per square mile	
Per cent of land area in farms	88.7
Per cent of farm land improved	64.3
Average acres per farm	136.8
Average improved acres per farm	87.9
Value of all farm property	$14,610,955
Per cent of increase 1900 to 1910	67.2
Value of all crops in 1909	$1,807,505
Cereals (wheat, corn, oats, barley, rye)	$1,380,174
Other grains and seeds	$4,808
Hay and forage*	$261,776
Vegetables	$51,012
Fruits and nuts	$14,146
All other crops	$95,589

* Tame grass, 17,148 tons; wild grass, 37,303 tons.

DAKOTA COUNTY

Dakota County, of which Hastings is the county seat, lies on the south side of the Mississippi, opposite and immediately below St. Paul. This county was settled rapidly in pioneer days, owing to its situation along a navigable stream. The growth in population since 1880 has been largely in the cities and villages. Its surface was in part prairie and in part covered by a light growth of oak forest which was easily cleared.

The county drains eastward to the Mississippi River, except a few square miles in the northwest end, which drains westward to the Minnesota River. The preglacial course of the Mississippi, as indicated by the well records, was a few miles south of its present course, and its bed is but little more than 500 feet above sea level. The present river has a bed 150 to 175 feet higher, the stream being about 670 feet where it leaves the county. A considerable part of the county has an altitude between 900 and 1,000 feet. The preglacial rock surface of this county, and that of neighboring parts of Washington, Goodhue, and Rice counties, was very uneven, there being isolated mesa-like uplands and buttes standing 100 to 200 feet above the surrounding lowland. A capping of limestone over soft sandstone protected the sandstone wherever it escaped erosion, while the unprotected sandstone was greatly broken down. The glacial deposits have only partially concealed the old escarpments of the mesas, and coated their table-like surfaces with a thin cover, except in the part of the county occupied by strong moraines of the red drift.

The moraines of young red drift are prominent in the northwest part of the county in the great bend of the Mississippi opposite St. Paul and Minneapolis. They are overlapped by the gray drift of the Keewatin ice field along the western edge of the county. Extensive red drift gravel plains run entirely across the county from west to east, and descend from an altitude of 900 feet or more to about 800 feet. The valleys of the Vermilion and Cannon rivers are also gravelly.

In the eastern part of the county an older red drift is extensively exposed, while in the southwestern part the old gray drift occupies the surface, except where covered with thin deposits of later drift and traversed by lines of glacial drainage from the newer drift.

A large part of the old red drift is loose-textured and gravelly, there being but a small admixture of clay. It includes a sharply ridged belt leading southeastward from Hampton nearly to the Cannon River. But as a rule its surface is nearly plane. The weathering of this drift is markedly greater than that of the young red drift; yet it seems to be of post-Kansan age, for it lies on the eroded surface of the Kansan drift, or old gray drift of the Minnesota reports.

The old gray drift contains a large amount of clayey till, but it has been leached of calcareous material to a depth of several feet, and thus differs from the young gray drift in which limestone pebbles are preserved nearly to the surface.

There are strips of loess in this county entirely isolated from the large loess-covered areas of southeastern Minnesota. One strip about a mile in average width runs from New Trier southeast to the southeast corner of the county. Another small loess area lies northwest of Farmington.

Percentages of Classes of Land in Dakota County

	Square miles	Per cent
Old red drift, prevailingly gravelly loam	96	16.03
Old gray drift, prevailingly clayey loam	60	10.01
Loess, pebbleless silt loam	26	4.34
Wisconsin red drift, stony clay loam	110	18.36
Wisconsin red drift outwash and glacial drainage, gravelly loam with partial cover of silt loam	118	19.70
Wisconsin gray drift, silty clay loam	62	10.35
Alluvium and marshy bottoms along the Minnesota and Mississippi rivers	28	4.67
Outwash and glacial drainage of Wisconsin gray drift	32	5.34
Sandy river terraces	7	1.17
Rock areas and very thin drift	30	5.00
Swamps and bogs (outside river valleys)	30	5.00
	599	99.99

Farm and Crop Data for Dakota County from Census of 1910

Rural population 11,249 or 18.7 per square mile

Per cent of land area in farms	86.0
Per cent of farm land improved	78.8
Average acres per farm	152.5
Average improved acres per farm	120.1
Value of all farm property	$22,986,004
Per cent of increase 1900 to 1910	94.9
Value of all crops in 1909	$3,177,701
Cereals (oats, corn, barley, wheat, rye)	$2,142,628
Other grains and seeds	$43,948
Hay and forage*	$483,710
Vegetables	$382,403
Fruits and nuts	$49,432
All other crops	$75,580

* Tame grass, 51,335 tons; wild grass, 11,047 tons.

GOODHUE COUNTY

Goodhue County borders the Mississippi River in southeastern Minnesota, with Red Wing as the county seat. Like Dakota County it was settled at an early date, the settlements being at first on the gravel terraces along the Mississippi and its tributaries, and soon after on the uplands.

The drainage is all eastward to the Mississippi, the north part being drained chiefly by Cannon River, and the south part by Zumbro River. The uplands are gently undulating to rolling, and are of the drainage erosion type, for this county lies outside the limits of the young or Wisconsin drift, and there has been developed a broad dendritic drainage in the old gray drift. Toward the eastern side of the county, however, the streams drop down into the deep preglacial drainage.

The uplands maintain a height of about 1,100 feet clear out to the Mississippi in the district below Red Wing, but are somewhat lower in the north part of the county. The southwest part of the county rises to 1,200 or 1,250 feet, but as the drift there is about 100 feet thick, the rock surface is about the same altitude as at the bluffs of the Mississippi. The bluffs are very precipitous, being formed largely of Paleozoic limestone, and rise 300 to 400 feet or more above the Mississippi and the lower courses of its tributaries. The Mississippi below Red Wing is expanded into Lake Pepin with an altitude of 664 feet at low water, and about 680 feet at high water stages.

Along the Mississippi and its main tributaries, Cannon River and Zumbro River, there are conspicuous deposits of fine gravel, laid down by glacial waters which escaped from the edge of the ice when it covered the upper parts of these valleys. Along the Mississippi the outlet of Lake Agassiz swept away a large part of this glacial gravel. The gravel was carried by the glacial waters into lowlands in and east of Red Wing that are outside the present course of the Mississippi but which open into the Mississippi at either end. The gravel filling reached about 800 feet above sea level in the vicinity of Red Wing, or 140 feet above Lake Pepin.

The northeast part of the county was forested, but the uplands of the central and southwest parts were prairie. A large part of the uplands has a capping of loess over the old gray drift. That in the forested part is of brown color, while that in the prairie is a dark, nearly black silt loam. The brown phase is classed by the Bureau of Soils as Knox silt loam, while the dark phase is called Marshall silt loam.[1]

A large part of the prairie portion of Goodhue County has no capping of loess, and the old gray drift is at the surface. It is largely a clayey till, and is classed by the Bureau of Soils as Carrington loam, silt loam, and fine sandy loam. In a few places gravelly knolls appear, the most conspicuous belt being immediately south and west of Zumbrota. These are classed as Miami silt loam, gravel hill phase. In some cases the slopes of these gravel hills have a capping of loess which throws the soil into the Knox series. About six square miles, however, were found to be gravelly at the surface. The gravel contains much limestone; in some cases this has been leached out to a depth of only a few inches, while in other cases it has been leached to a depth of several feet, leaving only the cherty parts to indicate its former presence.

---

[1] Soil Survey of Goodhue County. *Field operations of the Bureau of Soils* 1913.

There are a few square miles of old red drift exposed in the northern part of the county northwest of Welch. This is looser textured and more stony than the old gray drift which it overlies. But the Bureau of Soils classes this drift in the Carrington series.

The glacial gravel and sand of Wisconsin age is classed as Waukesha loam, gravelly sandy loam, etc., to correspond with the variations in coarseness of the soil.

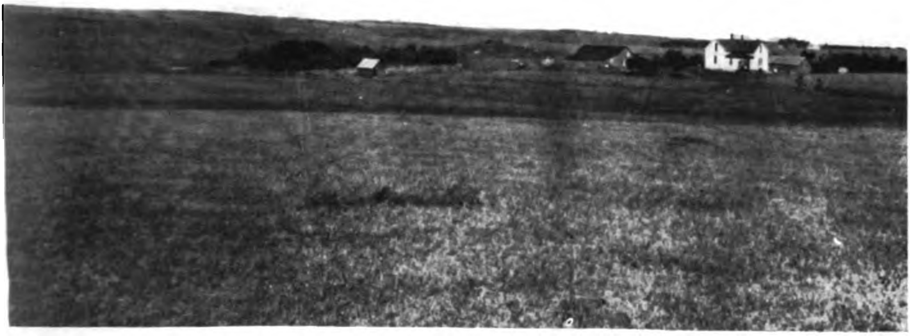
The low bottoms which are more or less subject to overflow are classed as Wabash silt loam, loam, or fine sandy loam, to correspond with variations in texture. The name Wabash silt loam, colluvial phase, is applied to material that is in process of transportation down small tributaries and gentle slopes into the main valleys. This often contains bowlders and other coarse material.

The rough stony land embraced in the steep bluffs is estimated by the Bureau of Soils to include 4.8 per cent of the county, but much of this is suitable for pasture, as it carries soil and disintegrating lime material that gives grasses a good growth.

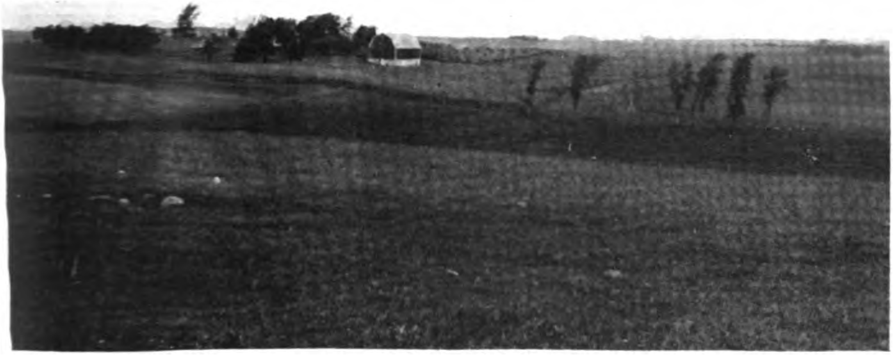
The loess soil of this region was for many years devoted to wheat growing, but of late barley has taken the place of wheat, while there has been a gradual change to diversified farming.

Area of Different Soils in Goodhue County (from Bureau of Soils Report)

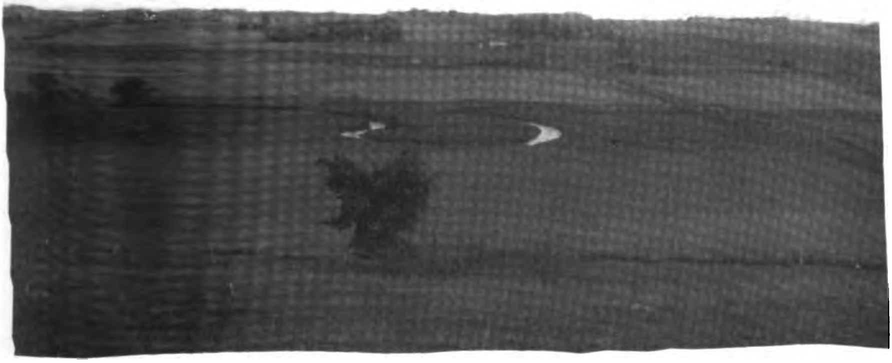
	Acres	Per cent
Knox silt loam (loess)	211,200	43.0
Wabash silt loam (alluvium)	19,648	4.0
Colluvial phase	25,344	5.2
Marshall silt loam (loess)	36,864	7.5
Carrington silt loam (old till)	32,448	6.6
Fargo silt loam (old till)	24,640	5.0
Rough stony land (rock bluffs)	23,552	4.8
Carrington loam (old till)	21,504	4.4
Miami silt loam (over glacial gravel)	16,768	3.4
Gravel hill phase	4,032	0.8
Waukesha silty clay loam (alluvial)	15,360	3.1
Carrington silty clay loam (old till)	13,696	2.8
Waukesha fine sandy loam (alluvial)	7,552	1.5
Waukesha loam (alluvial)	5,312	1.1
Red Wing loamy sand (colluvial)	5,184	1.1
Carrington fine sandy loam (old till)	4,672	1.0
Miami loamy sand (colluvial)	4,224	0.9
Miami fine sandy loam (colluvial)	4,160	0.9
Meadow (alluvial)	3,136	0.6
Wabash loam (alluvial)	2,112	0.4
Wabash fine sandy loam (alluvial)	2,048	0.4
Knox fine sandy loam (upland sand)	2,048	0.4
Waukesha loamy sand (alluvial)	1,600	0.3
Sogn clay loam (residuary)	1,472	0.3
Waukesha gravelly sandy loam (alluvial)	1,088	0.2
Wabash gravelly sandy loam (alluvial)	960	0.2
Plainfield silt loam (alluvial)	256	0.1
	490,880	100.0



A. SLOPE OF THE COTEAU DES PRAIRIES NEAR CANBY. GRAY DRIFT MORAINE



B. ERODED UPLAND IN OLD GRAY (KANSAN) DRIFT NORTHEAST OF ZUMBROTA



C. BROAD VALLEY CUT IN OLD GRAY (KANSAN) DRIFT WEST OF KENYON

UNIV OF

Farm and Crop Data for Goodhue County from Census of 1910

Rural population 17,403 or 22.7 per square mile

Per cent of land area in farms	94.1
Per cent of farm land improved	77.9
Average acres per farm	152.0
Average improved acres per farm	118.4
Value of all farm property	$32,266,663
Per cent of increase 1900 to 1910	78.8
Value of all crops in 1909	$3,997,787
Cereals (barley, oats, corn, wheat, rye)	$2,944,258
Other grains and seeds	$196,940
Hay and forage*	$618,554
Vegetables	$100,287
Fruits and nuts	$39,210
All other crops	$98,538

* Tame grass 100,403 tons; wild grass 8,627 tons.

RICE COUNTY

Rice County, with Faribault as its county seat, is located in southeastern Minnesota. The land area is 495 square miles, and there is an additional 21 square miles in lakes. The greater part of the county is drained by Cannon River northeastward to the Mississippi at Red Wing, but the southeast part is drained eastward by the Zumbro River. The northwest corner is drained northward to the Minnesota River.

About 100 square miles along the eastern side of the county lie outside the limits of the Wisconsin drift, and this old drift area comprises most of the prairie portion of the county. It also includes the highest land in the county which is found in the southeast part and reaches an altitude of nearly 1,300 feet. The western half of the county, even where occupied by sharp morainic ridges, is largely between 1,000 and 1,100 feet. The lowest land in the county is in the valley of Cannon River, which falls to about 900 feet at Northfield on the north edge of the county.

The old drift has an undulating surface produced by broad wide open drainage lines. These are excavated in the drift, except in the northeast corner of the county, where they drop into preglacial valleys and lowlands. In that part of the county there are a few flat-topped mesas in which limestone caps the soft St. Peter sandstone. The lowlands around these mesas are filled with an old gravel covered by a few feet of black loam soil. The mesas are generally covered to a depth of a few feet by a clayey till. The old gray drift of the eastern part of the county is chiefly a pebbly clay loam, classed by the Bureau of Soils as Carrington loam, and Carrington silt loam.[2] There are small loess-covered areas in it occupying about 8 square miles in the district between Northfield and Nerstrand. This is classed as Marshall loam by the Bureau of Soils.

---

[2] Soil Survey of Rice County. *Field Operations of the Bureau of Soils.* 1909.

Area of Different Soils in Rice County (from Bureau of Soils Report)

	Acres	Per cent
Carrington loam (chiefly moraine)	84,096	26.3
"Erosion phase" (rough moraine)	39,296	12.3
Meadow	40,832	12.8
Carrington silt loam (chiefly old till)	38,144	11.9
Fargo clay loam (chiefly Wisconsin till plain)	24,832	7.8
Fargo silt loam (chiefly Wisconsin till plain)	22,720	7.1
Peat	16,320	5.1
Carrington clay loam (chiefly moraine)	12,544	3.9
Carrington sandy loam (chiefly moraine)	11,840	3.7
Sioux sandy loam (glacial drainage)	10,752	3.4
Sioux silt loam (glacial drainage)	7,744	2.4
Marshall loam (loess)	4,992	1.5
Sioux gravelly loam (glacial drainage)	2,304	0.7
Boone sand (colluvial, residual)	2,240	0.7
Sioux fine sandy loam (glacial drainage)	1,344	0.4
	320,000	100.0

Farm and Crop Data for Rice County from Census of 1910

Rural population 11,813 or 24 per square mile

Per cent of land area in farms	94.0
Per cent of farm land improved	77.0
Average acres per farm	125.2
Average improved acres per farm	96.4
Value of all farm property	$22,753,492
Per cent of increase 1900 to 1910	60.2
Value of all crops in 1909	$2,914,736
Cereals (oats, wheat, corn, barley, rye)	$2,110,966
Other grains and seeds	$32,511
Hay and forage*	$463,143
Vegetables	$97,766
Fruits and nuts	$29,494
All other crops	$180,856

* Tame grass 51,260 tons; wild grass 35,628 tons.

A large part of Rice County is occupied by the system of moraines which were formed on the east side of the Keewatin ice field and run north to south across the county. Among the morainic ridges and knolls there are small till plains, but the moraines are woven together in an intricate manner. The soil of the moraines is classed in the Carrington series by the Bureau of Soils, while the till plains are chiefly Fargo silt loam, and Fargo clay loam, but part of the till plain is in the Carrington series. There are numerous peat bogs inclosed among the morainic knolls and ridges, and the depressions, when not peaty, have usually a darker colored soil than the bordering higher and better drained land.

The young gray drift overrode the moraines of the red drift in northern Rice County but made so heavy a deposit that the red drift is completely concealed. Red drift material, however, is found involved in the gray, either in masses or mixed more thoroughly. The red drift may in some cases have been carried farther south than its original position. Such seems to have been the case in an exposure noted on the Rock

Island Railroad at the north line of Cannon City Township, five miles north of Faribault.

The glacial outwash and glacial drainage deposits are classed by the Bureau of Soils as Sioux gravelly loam and Sioux sandy loam. The silt covered old gravel, in the northeast part of the county, is classed as Sioux silt loam.

LE SUEUR COUNTY

Le Sueur County is situated on the east side of the north flowing part of the Minnesota River in southern Minnesota, with Le Sueur Center as the county seat. The greater part of the county drains northwestward into the Minnesota, but the southeast corner is drained eastward by Cannon River to the Mississippi.

The eastern edge of the county is strongly morainic, and a prominent morainic spur extends westward past Elysian about 6 miles farther than the rest of the moraine. Between the moraine and the Minnesota valley is a till plain 10 to 15 miles wide with scarcely any knolls, but with numerous basins and small lakes. A line of glacial drainage heading at Elysian leads eastward through the moraine and down the Cannon valley.

The morainic area as well as the till plain is largely composed of clayey till with a pebbly clay loam soil. But in the morainic spur near Elysian there is a large amount of gravelly, loose-textured drift.

The Minnesota valley is about 250 feet deep along the border of this county, but part of it is filled with glacial drainage deposits of sandy gravel, the highest of which stand about 150 feet above the stream. These gravelly plains were occupied in part by prairie, but the remainder of the county was covered with hardwood forest. The outlet of Lake Agassiz removed a large part of the glacial gravel, and in places exposed rock ledges which appear along the valley up to a height of 50 to 75 feet or more above the stream.

Percentages of Classes of Land in Le Sueur County

	Square miles	Per cent
Gravel hills and stony loam in moraine	24	5.15
Moraine with pebbly clay loam soil	102	21.88
Till plain chiefly pebbly clay loam soil	280	60.08
Gravelly outwash and glacial drainage	25	5.38
Rock ledges in Minnesota valley	8	1.71
Alluvial bottoms with variable soil	17	3.65
Marshes and terrace swamps on uplands	10	2.15
	466	100.00

Farm and Crop Data for Le Sueur County from Census of 1910

Rural population 11,347 or 24.3 per square mile

Per cent of land area in farms	87.8
Per cent of farm land improved	62.3
Average acres per farm	118.1

Farm and Crop Data for Le Sueur County (Continued)

Average improved acres per farm	73.5
Value of all farm property	$20,048,441
Per cent of increase 1900 to 1910	80.2
Value of all crops in 1909	$2,473,797
Cereals (wheat, corn, oats, barley, rye)	$2,004,730
Other grains and seeds	$3,944
Hay and forage*	$248,044
Vegetables	$69,026
Fruits and nuts	$17,761
All other crops	$130,292

* Tame grass, 31,353 tons; wild grass, 35,664 tons.

NICOLLET COUNTY

Nicollet County is situated on the north side of the great bend of the Minnesota River in southern Minnesota, with St. Peter as its county seat. The drainage is all south or east to the Minnesota, but in much of the county natural drainage lines are poorly developed, and it has been necessary to extend ditches over such areas. There are several shallow lakes on the uplands occupying about 20 square miles, around which is marshy land with an additional 10 square miles. Ditching has, however, reduced the marshes and wet areas very materially.

The county is nearly all a prairie till plain with rich black loam soil and pebbly clay loam subsoil. A morainic strip with two somewhat distinct ridges or members leads across the western part of the county from Clear Lake past Klossner to the Minnesota valley at Cortland. The moraine has some knolls of gravel, but always with clay till surface.

The Minnesota valley is cut to a depth of about 200 feet below the bordering till plain. Near St. Peter, and also near Cortland, there is a wide remnant of a glacial gravel deposit, but generally the low bottom lands extend back to the bluffs. The glacial river that was the outlet of Lake Agassiz uncovered rock ledges in the east part of the county, and between Cortland and New Ulm.

Percentages of Classes of Land in Nicollet County

	Square miles	Per cent
Moraines largely clayey, pebbly clay loam	40	9.03
Till plains chiefly black clay loam	330	74.49
Upland marshes and bogs	10	2.25
Glacial gravel in Minnesota valley	9	2.03
Alluvial deposits in Minnesota valley	50	11.28
Rock outcrops in Minnesota valley	4	0.91
	433	99.99

Farm and Crop Data for Nicollet County from Census of 1910

Rural population 7,929 or 17.9 per square mile

Per cent of land area in farms	92.5
Per cent of farm land improved	72.3
Average acres per farm	185.4
Average improved acres per farm	134.1
Value of all farm property	$15,863,289

Farm and Crop Data for Nicollet County (Continued)

Per cent of increase 1900 to 1910	56.2
Value of all crops in 1909	$2,349,362
Cereals (wheat, corn, oats, barley, rye)	$1,951,541
Other grains and seeds	$10,597
Hay and forage*	$264,330
Vegetables	$60,216
Fruits and nuts	$14,639
All other crops	$48,039

* Tame grass, 17,610 tons; wild grass, 54,967 tons.

BROWN COUNTY

Brown County, of which New Ulm is the county seat, lies on the south side of the Minnesota valley in southern Minnesota. The drainage is all eastward into the Minnesota chiefly through Cottonwood and Little Cottonwood rivers. From an altitude of over 1,200 feet in the southwest corner of the county, the upland plain slopes gently northeastward to about 1,000 feet at the bluff of the Minnesota River. The river is in a valley 200 feet deep, and falls from 804 feet at the west line to about 780 feet at the east line of the county.

There are sharp moraines with well-defined outwash plains and lines of glacial drainage crossing the southwest part of the county. There is also a moraine traversing the central part of the county from northwest to southeast. But the greater part of the county is a prairie till plain with rich black loam soil and pebbly clay loam subsoil. Forest is confined to narrow strips along the Cottonwood and Minnesota valleys. Gravel knolls occur here and there on the plain, and they are numerous in the moraines. The gravelly outwash plains of the southwest part of the county are continued eastward in lines of glacial drainage which form a network of channels leading across from the Little Cottonwood to the Watonwan River. Their courses were determined by the edge of the ice, and not by the most rapid slope of the land. The present streams are more nearly adjusted to the general slope of the country. The Minnesota valley has small remnants of a filling with glacial gravel to a height of over 100 feet above the river. The city of New Ulm stands on one of these remnants.

Percentages of Classes of Land in Brown County

	Square miles	Per cent
Gravelly knolls chiefly in moraines, stony loam	8	1.30
Moraines of clayey till, pebbly clay loam	75	12.25
Till plain with black clay loam soil	460	75.16
Outwash gravel and sand and glacial deposits	40	6.53
Gravel terraces along Minnesota valley	2	0.32
Alluvial bottoms of Minnesota valley	24	3.92
Bare rock in Minnesota bottoms	3	0.49
	612	99.97

Farm and Crop Data for Brown County from Census of 1910

Rural population 10,010 or 16.35 per square mile	
Per cent of land area in farms	93.3
Per cent of farm land improved	84.2
Average acres per farm	202.2
Average improved acres per farm	170.3
Value of all farm property	$20,999,282
Per cent of increase 1900 to 1910	57.5
Value of all crops in 1909	$2,930,658
Cereals (wheat, corn, oats, barley, rye)	$2,445,529
Other grains and seeds	$29,067
Hay and forage*	$330,596
Vegetables	$70,266
Fruits and nuts	$12,788
All other crops	$42,412

* Tame grass, 20,657 tons; wild grass, 71,440 tons.

REDWOOD COUNTY

Redwood County is situated on the south side of the Minnesota valley in southern Minnesota, with Redwood Falls as the county seat. The drainage is all eastward to the Minnesota River, chiefly through Redwood and Cottonwood rivers. The county is largely a plain standing between 1,000 and 1,200 feet, but the southwest corner rises to about 1,400 feet. The Minnesota valley is cut to a depth of 200 feet below the bordering plain, the river being 842 feet at the western, and 804 feet at the eastern limits of the county.

There are several moraines formed along the south edge and southeast end of the Keewatin ice field as it was melting back across the plain that borders the Minnesota River. One morainic belt is in the southwest corner of the county; another follows the north side of the Cottonwood, and another the north side of the Redwood valley. This last moraine splits into three narrow ridges that run southeastward through the eastern part of the county. There is also a later moraine in the extreme northwest corner of the county. The moraines are usually a clayey till, but in places gravel knolls become conspicuous. This is notably the case in the slender ridges in the east part of the county. There is a prominent strip of gravel knolls and ridges immediately east and south of Revere, which trends southwestward toward a moraine in Cottonwood County, instead of paralleling the course of moraines of this region. It is not, however, a definite gravel or esker ridge, but has much irregularity of form and of structure, for considerable till is included with the gravel.

Glacial drainage seems to have been rather weak along the border of the moraines, and deposits of sand and gravel are scanty. It is probable that the water was ponded in places along the edge of the ice during the development of some of the moraines. The plains bordering the moraines have a rich black clay loam soil, as this was a prairie region.

The moraines have a brown clay loam soil where most prominent, but the parts with a gentle slope have a darker soil.

Rock outcrops are conspicuous along the Minnesota River and up Redwood valley as far as Redwood Falls. The granite is in places capped by cretaceous deposits in the river bluffs, but is generally swept bare in the valleys. It rises in places fully 100 feet above the stream, and at Redwood Falls attains an altitude of nearly 200 feet above the Minnesota River, or 1,000 feet above sea level. The Minnesota valley has in this county but little good farm land because of the extensive outcrops of ledges, and because portions of it are subject to overflow.

Percentages of Classes of Land in Redwood County

	Square miles	Per cent
Gravelly knolls and ridges, partly morainic, stony loam	10	1.13
Clayey moraine, brown to black pebbly clay loam	150	17.03
Border drainage with sandy deposits	24	2.72
Till plain, black clay loam	670	76.05
Rock outcrops along Minnesota valley	15	1.70
Alluvial deposits along Minnesota valley	12	1.36
	881	99.99

Farm and Crop Data for Redwood County from Census of 1910

Rural population 12,760 or 14.5 per square mile

Per cent of land area in farms	93.5
Per cent of farm land improved	83.2
Average acres per farm	228.2
Average improved acres per farm	189.8
Value of all farm property	$30,231,266
Per cent of increase 1900 to 1910	83.3
Value of all crops in 1909	$3,745,360
Cereals (oats, corn, wheat, barley, rye)	$3,258,279
Other grains and seeds	$91,567
Hay and forage*	$295,639
Vegetables	$78,080
Fruits and nuts	$12,897
All other crops	$8,898

* Tame grass, 31,819 tons; wild grass, 59,116 tons.

LYON COUNTY

Lyon County is located in the southwest part of the state, with Marshall as the county seat. The drainage is all eastward into the Minnesota River, mainly through Redwood and Cottonwood rivers. A few townships in the southwest part are on the slope of the Coteau des Prairies with an altitude ranging from 1,750 feet down to about 1,300 feet. The remainder of the county stands mainly between 1,100 and 1,300 feet, and slopes gradually northeastward.

A prominent morainic system which was formed on the southwest side of the Keewatin ice field lies across the southwest part of the county, its several constituent members being ranged one below another on the slope of the Coteau des Prairies. Weaker moraines across the northeast part of the county run from northwest to southeast. One of them passes through Marshall and others cross the northeast corner of the county. All the moraines, whether weak or strong, are composed mainly of clayey till, and have a brown pebbly clay loam soil. The till plains which lie between the moraines have a black clay loam soil with pebbly clay loam subsoil.

There is remarkably little outwash gravel connected with the moraines in this county. A few gravel knolls occur near Balaton, and others near Russell. There are definite border drainage channels along the south side of the weak moraines in the northeast part of the county, which are in places covered to a slight depth with sand and fine gravel.

Percentages of Classes of Land in Lyon County

	Square miles	Per cent
Gravelly moraine, stony loam	25	3.53
Clayey moraine, pebbly clay loam	225	31.77
Till plain chiefly black clay loam	390	55.09
Outwash and sandy glacial drainage deposits	30	4.24
Marshy abandoned channels	18	2.54
Alluvial deposits	20	2.82
	708	99.99

Farm and Crop Data for Lyon County from Census of 1910

Rural population 9,064 or 12.8 per square mile	
Per cent of land area in farms	88.6
Per cent of farm land improved	85.7
Average acres per farm	238.7
Average improved acres per farm	204.6
Value of all farm property	$23,059,304
Per cent of increase 1900 to 1910	95.9
Value of all crops in 1909	$2,591,653
Cereals (oats, corn, barley, wheat, rye)	$2,132,612
Other grains and seeds	$90,961
Hay and forage*	$279,249
Vegetables	$59,925
Fruits and nuts	$7,606
All other crops	$21,300

* Tame grass, 31,439 tons; wild grass, 32,997 tons.

LINCOLN COUNTY

Lincoln County is situated on the west border of the state in southwestern Minnesota, and embraces a land area of 535 square miles, in addition to which there are 19 square miles in lakes. The county is crossed from the northwest to southeast by the crest of the Coteau des Prairies. The northeast slope of the Coteau is drained to the Minnesota, while the southwest is drained to the Big Sioux and thence to the Missouri River.

The crest of the Coteau is a moraine that leads southeastward through the southwest part of the county past the south end of Lake Benton. This moraine has three deep notches in it within the limits of this county, which permit drainage from its inner border to pass through it into the Sioux River system. The altitude of the highest points on the moraine is nearly 2,000 feet, and there are several square miles standing above 1,900 feet. The bordering till plains on each side of the moraine are also very elevated, much of their area in this county being above 1,800 feet. Glacial drainage lines led from this moraine southwestward into South Dakota to the Big Sioux valley.

The northeast half of Lincoln County is largely morainic, there being only narrow till plains between conspicuous ridges. These ridges are arranged one below another on the slope of the Coteau, the altitude of the outer ones being 1,700 to 1,800 feet, and of the inner 1,400 feet or less.

The strong moraines of this county include much loose-textured cobbly and bowldery drift, with a stony loam soil, but there are large sections with clayey till and only a moderate number of stones. The till plains have a pebbly clay loam soil.

Percentages of Classes of Land in Lincoln County

	Square miles	Per cent
Morainic drift with stony loam soil	75	14.02
Clayey moraine, pebbly clay loam	130	24.30
Till plains with stony loam soil	30	5.59
Till plains with black clay loam soil	268	50.10
Outwash plains and sandy glacial drainage	12	2.24
Marshes and bogs	20	3.74
	535	99.99

Farm and Crop Data for Lincoln County from Census of 1910

Rural population 7,429 or 14 per square mile	
Per cent of land area in farms	89.4
Per cent of farm land improved	81.4
Average acres per farm	234.8
Average improved acres per farm	191.2
Value of all farm property	$15,729,215
Per cent of increase 1900 to 1910	104.9
Value of all crops in 1909	$1,830,475
Cereals (oats, barley, wheat, corn, rye)	$1,333,054
Other grains and seeds	$194,437
Hay and forage*	$260,027
Vegetables	$37,860
Fruits and nuts	$2,967
All other crops	$2,130

* Tame grass, 32,203 tons; wild grass, 28,538 tons.

PIPESTONE COUNTY

Pipestone County is situated on the west border of southwestern Minnesota with Pipestone as the county seat. The drainage is nearly all southwestward to the Big Sioux River, but the northeast corner drains northeastward to the Minnesota River. The crest of the Coteau des Prairies forms the divide and is followed by the highest moraine of the young gray Keewatin drift across the northeast part of the county. The southwestern part of the county to the west and south of Pipestone City lies outside the limits of the Wisconsin drift.

The young gray or Wisconsin drift border is not marked by a continuous moraine in southwestern Minnesota, but has here and there a knolly or slightly ridged surface. The drift for several miles back from the border veneers the slopes of the eroded surface of the old gray or pre-Wisconsin drift. The present drainage lines follow in a general way the courses opened by the interglacial streams. This area as far back as the prominent moraine on the Coteau des Prairies is free from lakes, and nearly all the surface is well drained. But from the crest of the Coteau northeastward the later drift completely filled the interglacial valleys, except perhaps great depressions such as that occupied by Lake Benton, and its deposits are so irregular and uneven that undrained basins and lakes are common features.

Outside the limits of the Wisconsin drift is a greatly eroded till area with broad valley bottoms and gentle valley slopes. This has a scanty coating of wind-drifted silt-loam, but usually the till is within a few inches of the surface.

There is a thin silt deposit covering the Wisconsin or younger drift in places to a depth of 1 to 3 feet which seems to have been brought in from loess-covered areas on the southwest. This is somewhat more compact than the silt cover on the older drift, thus making a clay loam rather than a silt loam soil.

There are small areas of bare quartzite in the vicinity of Pipestone and southward into Rock County. The quartzite, however, is generally covered with a few feet of drift, sufficient for productive farming. The bare areas are only a few acres each, and the entire exposure probably does not exceed 2 square miles. There is about 100 square miles in which the quartzite is known to underlie the drift, usually within a depth of a few feet. This is mainly within the older drift area, but the north part lies within the limits of the younger drift.

Percentages of Classes of Land in Pipestone County

	Square miles	Per cent
Moraine with stony loam soil	23	4.90
Glacial drainage, gravelly loam	36	7.68
Till plain of Wisconsin drift, clay loam	308	65.67
Pre-Wisconsin till with silt loam soil	100	21.32
Bare rock areas	2	0.43
	469	100.00

Farm and Crop Data for Pipestone County from Census of 1910

Rural population 5,116 or 11 per square mile

Per cent of land area in farms	89.3
Per cent of farm land improved	93.5

Farm and Crop Data for Pipestone County (Continued)

Average acres per farm	254.0
Average improved acres per farm	237.4
Value of all farm property	$17,022,735
Per cent of increase 1900 to 1910	133.8
Value of all crops in 1909	$1,762,497
Cereals (oats, barley, corn, wheat, rye)	$1,397,123
Other grains and seeds	$65,914
Hay and forage*	$238,190
Vegetables	$58,787
Fruits and nuts	$2,024
All other crops	$459

* Tame grass, 39,410 tons; wild grass, 10,585 tons.

MURRAY COUNTY

Murray County, of which Slayton is the county seat, is located in the southwest part of the state, and has a land area of 704 square miles, with about 16 square miles additional in small lakes. The drainage of this county is in three different systems, the northeast part being drained northeastward to the Minnesota, the central and southeast parts southeastward by the Des Moines River, and the southwest part southwestward to the Big Sioux River.

The crest of the Coteau des Prairies runs through the western part of the county, and is followed by a strong moraine. Parts of the moraine rise above 1,900 feet, and much of it above 1,800 feet, but there is a gap in it at Chandler which is only 1,650 feet. A few square miles on the east side of this moraine drain westward through this gap toward the Big Sioux River. The drainage of the eastern slope is chiefly to the Des Moines River. In the southwest part of the county the moraine just referred to becomes double and continues so southeastward into Iowa. The inner member makes a sharp loop northeastward to Hadley before taking this southeastward course. In this loop it has much gravelly drift, but elsewhere is composed chiefly of clayey though rather stony till. The outer member and the united moraine is largely of stony character with a few gravel knolls and a stony loam soil. There is a narrow strip of outwash gravel on part of the outer border. There was also a strong glacial drainage down Chanarambie Creek from Chandler.

Outside the moraine just outlined a thin veneer of young Wisconsin drift is spread over the eroded surface of the old gray drift. It only partly fills the interglacial valleys cut in that drift. The soil in this area is a wind drifted silt loam, coating the till to a depth of only a few inches. The subsoil is a pebbly clay loam with fewer stones than on the moraine.

East of the moraine that forms the crest of the Coteau is a broad till plain covering more than half of the county, and having a rich black clay loam soil. Northeast of this plain is a strong morainic system coming in from the northwest and sweeping around the south and east side of

Lake Shetek. It then follows the east side of Des Moines River southeastward into Cottonwood County. It is separable into several ridges in the east part of the county. The general elevation of this moraine is about 300 feet lower than the crest of the Coteau, being between 1,500 and 1,600 feet above sea level. The moraine contains much stony drift all along its course in this county with occasional gravelly knolls. There was a weak outwash from the moraine into the Des Moines valley.

Another till plain several miles in width crosses the northeast part of the county. This has a rich black clay loam soil. Northeast of it, in the extreme northeast corner of the county, is another morainic system composed of several narrow ridges separated by swales or narrow plains. This moraine is less stony than the others and has a pebbly clay loam soil, while the soil in the swales is a black clay loam.

Percentages of Classes of Land in Murray County

	Square miles	Per cent
Loose-textured moraine, gravelly to sandy loam	125	17.75
Clayey moraine with pebbly clay loam soil	60	8.52
Till plain with stony loam soil	30	4.26
Till plain with black clay loam soil	410	58.24
Till plain with silt loam soil, west slope of Coteau	44	6.25
Sandy and gravelly outwash and glacial drainage	20	2.84
Marshes and bogs	15	2.13
	704	99.99

Farm and Crop Data for Murray County from Census of 1910

Rural population 8,741 or 12.4 per square mile	
Per cent of land area in farms	89.0
Per cent of farm land improved	88.7
Average acres per farm	244.5
Average improved acres per farm	216.9
Value of all farm property	$23,455,837
Per cent of increase 1900 to 1910	88.9
Value of all crops in 1909	$2,297,548
Cereals (oats, corn, barley, wheat, rye)	$1,760,449
Other grains and seeds	$147,930
Hay and forage*	$309,552
Vegetables	$69,949
Fruits and nuts	$6,792
All other crops	$2,876

* Tame grass, 44,654 tons; wild grass, 33,318 tons.

COTTONWOOD COUNTY

Cottonwood County is located in southwestern Minnesota with Windom as the county seat. About 200 square miles in the southwest part of the county is drained southward by Des Moines River. The remainder of the county is drained northeastward to the Minnesota River.

A quartzite ridge standing between 1,200 and 1,400 feet above sea level crosses its northeast part, and has numerous small exposures of bare rock. Elsewhere the county is heavily covered with glacial deposits.

There are several moraines crossing the county from northwest to southeast. Narrow strips of gravelly and sandy outwash follow the outer border of moraines in the southwest part of the county, while the line of glacial drainage follows down the Des Moines valley across Jackson County into Iowa. The moraines include occasional clusters of sharp gravelly knolls, but they are mainly of clayey till with a rich pebbly clay loam soil. In the north part of the county, in T. 108, R. 37W., there is a conspicuous belt of gravelly knolls running from Section 9 to Section 13, a distance of about 4 miles. The trend of this gravelly belt is parallel with the neighboring moraines both north and south of it, but it does not connect with a definite moraine, there being a till plain all around it.

The till plains, which occupy more than half the surface of the county, have a rich soil of dark color with a pebbly clay loam subsoil. .

Percentages of Classes of Land in Cottonwood County

	Square miles	Per cent
Gravelly knolls and coarse drift, stony loam	20	3.12
Clayey moraine with pebbly clay loam soil	145	22.65
Sandy and gravelly outwash and glacial drainage	25	3.91
Till plain chiefly pebbly clay loam	544	69.37
Bogs and marshes	6	0.94
	640	99.99

Farm and Crop Data for Cottonwood County from Census of 1910

Rural population 8,880 or 14 per square mile	
Per cent of land area in farms	90.7
Per cent of farm land improved	91.2
Average acres per farm	235.1
Average improved acres per farm	214.3
Value of all farm property	$21,613,731
Per cent of increase 1900 to 1910	90.8
Value of all crops in 1909	$2,423,676
Cereals (oats, corn, barley, wheat, rye)	$1,960,152
Other grains and seeds	$137,317
Hay and forage*	$249,671
Vegetables	$54,993
Fruits and nuts	$14,931
All other crops	$7,612

* Tame grass, 31,625 tons; wild grass, 43,956 tons.

WATONWAN COUNTY

Watonwan County is situated in the southern part of the state, with St. James as the county seat. The county is drained to the Minnesota River, almost entirely by Watonwan River and its tributaries. The altitude is nearly all between 1,000 and 1,200 feet, but the southwest corner reaches about 1,300 feet, and part of Watonwan valley is below 1,000 feet.

Several weak moraines cross the county from northwest to southeast. They are rather diffuse knolly strips with flat areas among the knolls. They are composed largely of clayey till but there are occasional gravelly knolls.

The greater part of the county is a till plain with a rich black clay loam soil. There is, however, an area of about 30 square miles immediately northeast of St. James in which the soil is sandy.

Border drainage channels, lying just outside a moraine in the northwest part of the county have sandy and somewhat marshy surface. They are not so well developed in the south part of the county. There may have been a ponding of water there along the border of the ice. Such ponding is suggested by the presence of a general coating of silt a few inches in depth over the pebbly till immediately outside the moraines. The marsh lands of the county are chiefly along the lines of border drainage.

Percentages of Classes of Land in Watonwan County

	Square miles	Per cent
Gravelly knolls and stony parts of moraines, stony loam	10	2.30
Clayey moraine with pebbly clay loam soil	90	20.74
Sandy outwash and glacial drainage, sandy loam	20	4.61
Till plains with thin sandy coating	30	6.91
Till plains with clay loam soil	270	62.21
Swamps and bogs	14	3.22
	434	99.99

Farm and Crop Data for Watonwan County from Census of 1910

Rural population 7,135 or 16.4 per square mile	
Per cent of land area in farms	90.6
Per cent of farm land improved	89.7
Average acres per farm	198.3
Average improved acres per farm	178.0
Value of all farm property	$16,300,220
Per cent of increase 1900 to 1910	70.4
Value of all crops in 1909	$1,901,576
Cereals (oats, corn, wheat, barley, rye)	$1,528,960
Other grains and seeds	$32,144
Hay and forage*	$272,911
Vegetables	$41,909
Fruits and nuts	$13,197
All other crops	$12,375

* Tame grass, 30,397 tons; wild grass, 38,534 tons.

BLUE EARTH COUNTY

Blue Earth County is located in the southern part of the state south of the big bend of Minnesota River, and Mankato is the county seat. The drainage is all northward into the Minnesota, and the lower courses of several streams which converge toward the Minnesota at Mankato have deep valleys which have been utilized by certain railway lines in rising from the Minnesota valley to the upland plain. The greater part of the county is a plain standing between 1,000 and 1,100 feet above sea level. The immediate bluffs of the Minnesota are 975 to 1,000 feet, but the river is only 756 feet at Mankato.

In the northwest part of the county along and north of the Watonwan River there is a morainic belt with two more or less distinct ridges or members. Its soil is classed as Marshall loam and Marshall fine sandy loam in the report on that county by the U. S. Bureau of Soils.[8] Associated with this moraine are sandy deposits that have been distributed in part by the wind from the glacial outwash. The outwash seems to have been sand. There was probably more or less ponding of the waters in the vicinity of the great bend of the Minnesota at the time the moraine was forming, as the Minnesota valley below there had not yet been deeply excavated.

The greater part of the county is a plain with a clay loam to silt loam soil, classed by the Bureau of Soils as Marshall clay loam and Marshall silt loam. The clay loam is in parts of the county where the till is practically at the surface. The silt loam is where it has a thin coating of nearly pebbleless silt. Very flat parts of the till plain, whether covered with silt or not, usually have a black soil, and this is classed as Fargo clay or Fargo clay loam. The silt which covers the till is seldom more than 2 or 3 feet in thickness, and seems to have been laid down, as already noted, in the ponded waters which occupied the plain for a brief time during the opening of the Minnesota valley. These waters appear to have found outlet for a short time northeastward past Elysian to Cannon River. The duration of the ponded condition was so brief, however, that no definite shore lines appear to have been developed.

There are sharp gravel knolls in the south part of the county in two small groups. One group is 2 to 3 miles northeast of Amboy, and another about 5 miles west of that village. These knolls rise 50 to 75 feet above the level of the bordering plain and exceed 1,100 feet above sea level. In the extreme northeast corner of the county are also gravelly hills which rise above 1,100 feet.

Area of Different Soils in Blue Earth County (from Report of Bureau of Soils, 1906)

	Acres	Per cent
Marshall clay loam (pebbly clayey till plain)	185,152	38.7
Marshall silt loam (till with thin silt cover)	128,704	26.9
Fargo clay (flat silt covered till)	27,968	5.8
Fargo clay loam (flat silt covered till)	23,936	5.0
Upland meadows	19,264	4.0
Marshall fine sand (partly dune sand)	15,872	3.3
Wabash fine sandy loam (alluvial)	14,528	3.0
Marshall fine sandy loam (includes much of moraine)	13,824	2.9
Wabash silt loam (alluvial)	13,312	2.8
Marshall loam (chiefly moraine)	8,768	1.8
Fargo fine sandy loam (partly low areas in moraines)	7,680	1.6
Peat	7,680	1.6
Mankato sand (glacial drainage)	4,032	0.9

---

[8] Soil Survey of Blue Earth County. *Field Operations of the Bureau of Soils 1906.*

Area of Different Soils in Blue Earth County (Continued)

Judson loam (alluvial cones, etc.)	3,968	0.8
Mankato sandy loam (on rock ledges)	2,816	0.6
Mankato loam (on rock ledges)	1,600	0.3
	479,104	100.0

Farm and Crop Data for Blue Earth County from Census of 1910

Rural population 15,076 or 20 per square mile

Per cent of land area in farms	92.0
Per cent of farm land improved	80.0
Average acres per farm	152.6
Average improved acres per farm	122.0
Value of all farm property	$32,619,319
Per cent of increase 1900 to 1910	48.4
Value of all crops in 1909	$3,974,042
Cereals (wheat, corn, oats, barley, rye)	$3,225,658
Other grains and seeds	$22,694
Hay and forage*	$441,325
Vegetables	$139,904
Fruits and nuts	$49,003
All other crops	$95,458

* Tame grass, 58,960 tons; wild grass, 55,309 tons.

WASECA COUNTY

Waseca County is located in the southern part of the state, with Waseca as the county seat. Nearly all the county is drained westward by Le Sueur River to the Minnesota; but a few square miles on the north edge are tributary to Cannon River which drains eastward to the Mississippi.

A strong moraine runs from north to south through the eastern part of the county, but the remainder is a till plain. The moraine contains occasional gravel knolls but is mainly a clayey till. The till plain has a black clay loam soil with pebbly clay loam subsoil. The lower part of this plain has a coating of silt that seems referable to ponded glacial waters. These appear to have found outlet northeastward past Elysian to Cannon River. There is a well defined channel connecting Lake Elysian with the Cannon River drainage in southern Le Sueur County. The present outlet of Lake Elysian is in the opposite direction and leads to Le Sueur River and the Minnesota.

Percentages of Classes of Land in Waseca County

	Square miles	Per cent
Moraine chiefly clayey till, pebbly clay loam	121	36.56
Till plain, black clay loam slightly pebbly	200	60.42
Marshes and bogs	10	3.02
	331	100.00

Farm and Crop Data for Waseca County from Census of 1910

Rural population 8,554 or 20 per square mile

Per cent of land area in farms	92.9
Per cent of farm land improved	80.6
Average acres per farm	163.6

Farm and Crop Data for Waseca County (Continued)

Average improved acres per farm	131.8
Value of all farm property	$17,289,607
Per cent of increase 1900 to 1910	38.3
Value of all crops in 1909	$2,158,781
Cereals (wheat, corn, oats, barley, rye)	$1,734,609
Other grains and seeds	$23,871
Hay and forage*	$290,891
Vegetables	$56,627
Fruits and nuts	$15,224
All other crops	$37,559

* Tame grass, 26,340 tons; wild grass, 53,617 tons.

STEELE COUNTY

Steele County is located in southern Minnesota with Owatonna as the county seat. The drainage is nearly all northward through Straight River to Cannon River and thence to the Mississippi. A few square miles on the western edge drain westward to the Minnesota River. A few square miles on the eastern edge drain eastward by branches of the Zumbro to the Mississippi. The extreme southeast part drains to the Cedar River and thence southward through Iowa to the Mississippi.

The county is traversed by moraines trending north to south which were formed on the eastern side of the Keewatin ice field. There are small outwash gravel plains along the eastern or outer border of each moraine. There are also narrow strips of till plain between the moraines. Marshes of considerable extent occur on outwash plains in the southern part of the county, and on till plains in the northern part. Their original extent has, however, been somewhat reduced by ditching.

The moraines are composed largely of clayey till, but a prominent moraine in the southeast part of the county contains considerable gravel. The outwash and glacial drainage deposits are generally a rather light sandy gravel. The till plains have a rich black clay loam soil with pebbly clay loam subsoil.

Percentages of Classes of Land in Steele County

	Square miles	Per cent
Gravelly and stony moraine, stony loam	12	2.78
Clayey moraine, pebbly clay loam	144	33.41
Outwash and glacial drainage, sandy loam	36	8.35
Till plain, black clay loam	219	50.81
Marshes	20	4.64
	431	99.99

Farm and Crop Data for Steele County from Census of 1910

Rural population 9,373 or 21.7 per square mile

Per cent of land area in farms	95.2
Per cent of farm land improved	85.8
Average acres per farm	143.9
Average improved acres per farm	123.6
Value of all farm property	$19,032,988
Per cent of increase 1900 to 1910	46.8

Farm and Crop Data for Steele County (Continued)

Value of all crops in 1909	$2,548,707
Cereals (wheat, corn, oats, barley, rye)	$1,611,384
Other grains and seeds	$26,310
Hay and forage*	$404,707
Vegetables	$74,575
Fruits and nuts	$18,895
All other crops	$412,836

* Tame grass, 37,286 tons; wild grass, 48,647 tons.

DODGE COUNTY

Dodge County is situated in the southeast part of the state with Mantorville as the county seat. The drainage of nearly all of the county is eastward by branches of Root and Zumbro rivers to the Mississippi, but the southwest part is drained southward by Cedar River through Iowa.

The eastern edge of the young Wisconsin drift lies near the west border of the county. It is marked by a chain of low knolls and very thin deposits of young till. The knolls are in some cases gravelly, but clayey till prevails.

The pre-Wisconsin or old gray drift was originally a till plain, and in the western part of the county the plain is still well preserved, but in the eastern part it has become greatly eroded, and the surface now is occupied by broad, shallow valleys with gentle slopes. There are a few gravelly knolls, but chiefly in the southeast part. Gravel is also found along the Cedar valley in the southwest part, but there the surface is nearly plane.

Small areas in the northeast part of the county are covered with loess to a depth of several feet. The loess is in spur-like extensions westward from the main loess area in Olmsted County.

In the beds of the shallow valleys, bowlders are in places very numerous, as if concentrated by erosion. They are rare on divides, or on the remnants of the original plain.

The soil on the flat divides and level parts of the upland plain is generally a heavy black clay loam, while on the slopes it is looser textured with a larger admixture of pebbly material.

Percentages of Classes of Land in Dodge County

	Square miles	Per cent
Pre-Wisconsin till, chiefly pebbly clay loam	350	79.54
Pre-Wisconsin gravel, gravelly loam	8	1.82
Loess	33	7.50
Wisconsin till, chiefly clay loam	32	7.27
Wisconsin glacial drainage, gravelly loam	12	2.73
Marshes	5	1.13
	440	99.99

Farm and Crop Data for Dodge County from Census of 1910

Rural population 8,350 or 19 per square mile

Per cent of land area in farms	93.0
Per cent of farm land improved	86.5
Average acres per farm	165.0
Average improved acres per farm	142.8
Value of all farm property	$17,410,051
Per cent of increase 1900 to 1910	80.5
Value of all crops in 1909	$1,830,210
Cereals (barley, oats, corn, wheat, rye)	$1,175,703
Other grains and seeds	$173,979
Hay and forage*	$363,432
Vegetables	$56,298
Fruits and nuts	$15,799
All other crops	$44,999

* Tame grass, 62,826 tons; wild grass, 8,079 tons.

OLMSTED COUNTY

Olmsted County, of which Rochester is the county seat, is located in the southeast part of the state. The drainage of the eastern part of the county is eastward by Whitewater River; of the central and northwest parts northeastward by the Zumbro River; and of the southern part eastward by Root River to the Mississippi. The divides separating these three river systems rise in places slightly above 1,300 feet, and the greater part of the county is between 1,200 and 1,300 feet. The valleys are cut to a much lower level, and the Zumbro River falls below 900 feet at the north edge of the county. The principal streams are bordered by prominent rock bluffs, but the uplands are gently undulating. The cover of drift is generally thin. There are many sink holes in the limestone in the southern part of the county.

The drift is all of pre-Wisconsin age and has suffered considerable leaching and weathering. It is generally a stiff clayey till which becomes calcareous below the leached part at a depth of 4 to 6 feet.

Large gravel knolls occur in the line of an old valley in southern Oronoko Township, and there are smaller ones here and there in the central and western part of the county, and very rarely in the eastern part. Most of the drift in the valleys and lowlands is loose-textured, both in the low bottoms and on terraces.

Loess deposits form a coating widely over the till in the northeast quarter of the county and in several of the southern townships, but in the remainder of the county it is in isolated strips. A belt of land several miles wide running eastward from Rochester into Winona County is free from loess,—the land both to the north and south of it being widely loess covered.

Percentages of Classes of Land in Olmsted County

	Square miles	Per cent
Old till, pebbly clay loam	250	37.54
Old gravel knolls, stony loam	20	3.00
Loess	320	48.05
Valley terraces and bottoms, gravelly or sandy loam	60	9.01
Rough stony land in bluffs	16	2.40
	666	100.00

Farm and Crop Data for Olmsted County from Census of 1910

Rural population 12,381 or 19 per square mile

Per cent of land area in farms	92.3
Per cent of farm land improved	80.3
Average acres per farm	170.4
Average improved acres per farm	136.9
Value of all farm property	$27,137,633
Per cent of increase 1900 to 1910	44.1
Value of all crops in 1909	$2,994,191
Cereals (barley, oats, corn, wheat, rye)	$2,009,379
Other grains and seeds	$172,437
Hay and forage*	$495,623
Vegetables	$115,557
Fruits and nuts	$29,894
All other crops	$81,301

* Tame grass, 77,591 tons; wild grass, 5,478 tons.

WABASHA COUNTY

Wabasha County, with Wabasha as the county seat, borders the Mississippi in southeastern Minnesota. The drainage is all to the Mississippi and chiefly through Zumbro River. The highest altitude of the uplands is remarkably uniform, the dividing ridges being between 1,100 and 1,200 feet above sea level over nearly all the county. The immediate bluffs of the Mississippi are generally over 1,100 feet, or fully 450 feet above the stream, which is 664 feet above sea level at Lake Pepin and about 650 feet where it leaves the county.

Over much of the uplands there is a mere trace of drift with scattered pebbles and bowlders, but in places it reaches 40 feet or more. Leaching ordinarily extends to a depth of at least 6 feet, below which the till is somewhat calcareous.

There are knolls and drift ridges on the uplands in the northwest corner of the county a few miles southwest of Lake City. These are partly of gravel but contain much till. The highest ones rise 50 to 75 feet above the bordering plains, but the usual height is 20 to 30 feet. They may mark an old ice border, the ice being on the southwest side of the belt, but it is not traceable for more than 10 miles.

The uplands of Wabasha County are covered with loess and it extends down on the slopes of the main valleys nearly to the streams where these slopes are gentle, but in many cases the valleys have precipitous rock bluffs.

The valley bottoms, even of the small tributaries of the Mississippi, are broad and have a rich soil. The small tributaries carry a slack water filling of silt formed during the filling up or aggradation of the Mississippi by glacial drainage deposits, which reached a height of more than 100 feet above the present Mississippi, or to 775 to 800 feet above sea level. The filling along the Mississippi is a sandy gravel with only a slight cover of silt or loam. There is a similar filling along the Zumbro and its several branches. It is now preserved in narrow terraces along the valley borders of the Mississippi.

The early settlements were on the gravel terraces along the rivers, but soon were extended into the interior as the forests were largely oak openings easily cleared, and the southwest part of the county was prairie. The river transportation, which was the sole line in pioneer days, and later supplanted to some extent by railway lines, is still of considerable importance.

Percentages of Classes of Land in Wabasha County

	Square miles	Per cent
Ridges and knolls of pre-Wisconsin drift, stony loam	10	1.85
Loess covered uplands and slopes	380	70.24
Rough stony land in rock bluffs	46	8.50
Bottom land and terraces of small tributaries, silt loam soil	15	2.77
Gravel and sand deposits of Mississippi and Zumbro valleys, sandy to gravelly loam	65	12.01
Wet alluvial lands chiefly along Mississippi	25	4.62
	541	99.99

Farm and Crop Data for Wabasha County from Census of 1910

Rural population 9,448 or 17.5 per square mile	
Per cent of land area in farms	92.7
Per cent of farm land improved	71.6
Average acres per farm	179.6
Average improved acres per farm	128.5
Value of all farm property	$19,702,340
Per cent of increase 1900 to 1910	63.1
Value of all crops in 1909	$2,736,692
Cereals (barley, oats, corn, wheat, rye)	$1,991,640
Other grains and seeds	$96,940
Hay and forage*	$343,904
Vegetables	$138,553
Fruits and nuts	$30,019
All other crops	$135,636

* Tame grass, 53,890 tons; wild grass, 5,052 tons.

WINONA COUNTY

Winona County, of which Winona is the county seat, borders the Mississippi River in southeastern Minnesota. The entire county is drained northeastward or eastward into the Mississippi, much of it by short tributaries heading within the county. The uplands stand 1,200 to

1,300 feet above sea level, the immediate bluffs of the Mississippi being generally above 1,200 feet.

There is very little glacial material in the county, yet the presence of foreign pebbles and occasional bowlders on the uplands indicates that glaciation once extended over nearly all the county, there being only a few square miles in the southeast part in which drift pebbles have not been noted.

The uplands are covered by loess, except a narrow strip that extends from St. Charles eastward past Utica and thence southeast to Fremont. The part between Utica and Fremont has a light sandy soil from the breaking down of the sandstone formation which underlies it. To the west of Utica the soil is more clayey, being derived to some extent from the disintegration of limestone. In the loess-covered portion there is generally a reddish brown residuary clay between the rock and the loess. The glacial pebbles and bowlders are often imbedded in this residuary clay, which was evidently disturbed to some extent by the overriding ice.

The valleys are often bordered by precipitous rock bluffs, but even the small tributaries have wide bottom lands with a fertile soil. The Mississippi valley had been filled by sand and gravel to a level more than 100 feet above the present stream, and the tributaries were graded to a corresponding height. The glacial river which flowed from the outlet of Lake Agassiz removed much of the filling from the Mississippi valley, but in the tributaries it is still present in large amount.

At the time of settlement, the greater part of the county had a somewhat open forest which was easily cleared, and the southwest part was prairie. Farms were therefore rapidly developed on the uplands as well as in the Mississippi bottoms.

Percentages of Classes of Land in Winona County

	Square miles	Per cent
Upland without loess, soil with underlying rock	27	4.24
Loess covered uplands and slopes	500	78.45
Rough stony land in river bluffs	40	6.28
Gravel and sand deposits of the Mississippi valley	20	3.14
Low alluvial flats of the Mississippi valley	15	2.35
Alluvial and colluvial material in tributary valleys	35	5.49
	637	99.99

Farm and Crop Data for Winona County from Census of 1910

Rural population 12,070 or 19 per square mile

Per cent of land area in farms	91.8
Per cent of farm land improved	63.5
Average acres per farm	174.8
Average improved acres per farm	111.0
Value of all farm property	$22,718,884
Per cent of increase 1900 to 1910	58.1
Value of all crops in 1909	$2,712,087

Farm and Crop Data for Winona County (Continued)

Cereals (barley, oats, corn, wheat, rye)	$1,905,936
Other grains and seeds	$69,871
Hay and forage*	$437,321
Vegetables	$140,143
Fruits and nuts	$43,060
All other crops	$115,756

* Tame grass, 70,052 tons; wild grass, 1,473 tons.

HOUSTON COUNTY

Houston County is the southwest corner county of Minnesota, with Caledonia as the county seat. The drainage is eastward into the Mississippi, more than half of it being through Root River. The southern edge of the county drains to Upper Iowa River. Much of the upland stands between 1,100 and 1,200 feet above sea level, and maintains a height of 1,100 feet to the brow of the Mississippi bluff. A ridge southwest of Caledonia rises slightly above 1,300 feet. The erosion is broad along many of the valleys, and bottom lands are extensive. The breaking down of the upland is so great that it is preserved only in narrow strips between drainage lines. There are broad rock shelves at various levels on the slopes.

The western part of the county bears evidence of glaciation in the occurrence of bowlders and small pebbles of foreign rocks; but there is little or no till preserved, and the topography is essentially the same as in the driftless area.

Loess covers the uplands except on a few sharp ridges and knobs,—the high ridge southwest of Caledonia being nearly free from it. It is present on gentle slopes, and on the rock shelves bordering the valleys. It rests on a very gummy residuary clay, formed from the decomposition of the limestone, but is itself porous and highly productive.

The Mississippi valley had been filled to a height of about 100 feet above the present stream by sand and gravel, but at the last or Wisconsin glacial stage this filling was removed largely by the glacial river from Lake Agassiz. Small tributary valleys silted up to correspond with the filling on the Mississippi. The alluvial deposits of Root River have a gentle down stream slope and are of fine sand.

Percentages of Classes of Land in Houston County

	Square miles	Per cent
Loess	250	43.86
Bare slopes with residuary sand and clay	150	26.32
Rough stony land in bluffs	35	6.14
Valley filling, sandy gravelly loam	103	18.07
Wet Mississippi bottoms	32	5.60
	570	99.99

Farm and Crop Data for Houston County from Census of 1910

Rural population 10,472 or 18.4 per square mile

Per cent of land area in farms	89.7
Per cent of farm land improved	53.2
Average acres per farm	171.1
Average improved acres per farm	91.0
Value of all farm property	$16,836,250
Per cent of increase 1900 to 1910	69.3
Value of all crops in 1909	$1,979,513
Cereals (corn, oats, barley, wheat, rye)	$1,291,525
Other grains and seeds	$27,905
Hay and forage*	$426,089
Vegetables	$76,067
Fruits and nuts	$27,261
All other crops	$130,666

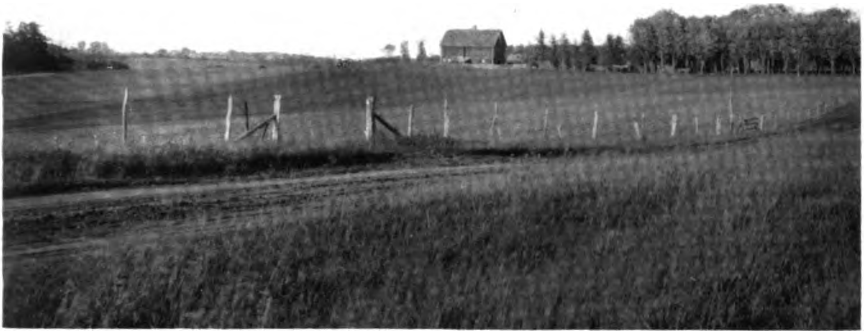
* Tame grass, 63,514 tons; wild grass, 2,303 tons.

FILLMORE COUNTY

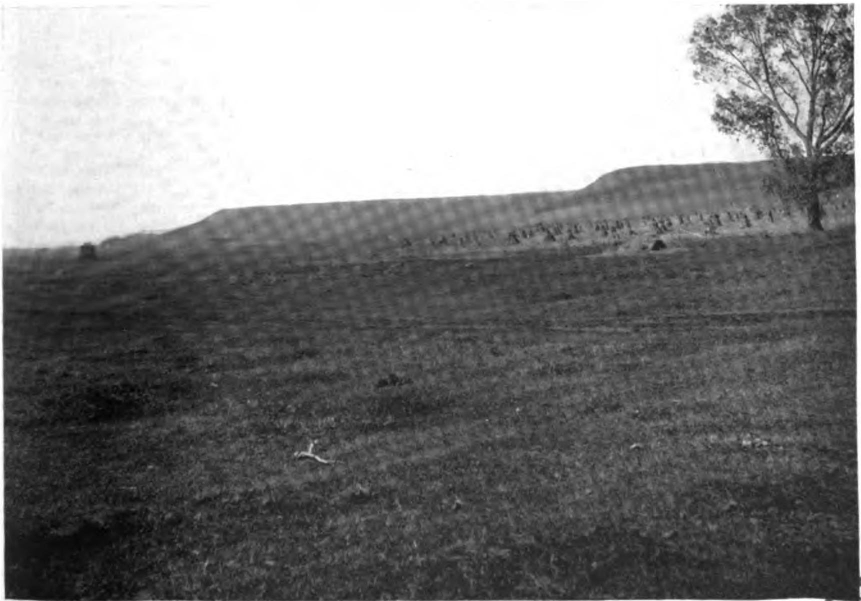
Fillmore County is the second from the Mississippi on the southern border of the state, with Preston as its county seat. The drainage of nearly all the county is eastward through Root River to the Mississippi, but a few square miles on the southern edge drain southward to the upper Iowa River which enters the Mississippi just south of the state line. The valleys are shallow in the southwest part of the county with bluffs of glacial material; but elsewhere they are cut deeply into hard rock formations and usually have steep bluffs. There are broad rock shelves along the valley sides which greatly widen out the space between uplands on opposite sides of streams. Only narrow strips come up to the height of the upland plain. The remnants of this upland plain stand 1,300 to 1,375 feet above sea level in the western and southern part of the county, and but little below 1,300 feet in the remainder. The valleys in the east part are very deep, and Root River falls to 712 feet at the east line of the county.

Although the entire county has been glaciated it is only along the western edge of the county that thick deposits of glacial drift occur, there being in the remainder of the county only scattered bowlders and pebbles and an occasional small and thin deposit of till or gravel. The remaining deposits in the southwest part of the county are sufficient to fill up preglacial valleys 150 to 200 feet deep and make a thin coating on the preglacial divides. This heavy drift contains a blue calcareous till, but its surface is leached of limestone to a depth of several feet, and the till is of yellow color for about 15 feet. It is generally compact and clayey but has a rich clay loam soil.

In places, beds of quartz pebbles, much older than the glacial deposits, cover the limestone and form a conspicuous element in the soil. They are abundant in the vicinity of Granger and of Ostrander, and northward along the western edge of the county on preglacial divides.



A. LOESS-COVERED DRIFTLESS AREA NEAR CALEDONIA



B. VALLEYS BORDERED BY LIMESTONE TABLELANDS NEAR HAMPTON

UNIV. OF MICH.

The uplands are loess-covered, except in the western end of the county, and have a rich silt loam soil. The loess is usually 10 to 15 feet thick and is present on rock shelves and gentle valley slopes as well as on high uplands. Much of the area of thick drift in the southwest part of the country is free from loess, and so is part of the thin drift area to the east.

The valleys are much narrower in this county than in Houston, being nearer the heads of the preglacial drainage lines. Terraces of sand and gravel are present along them.

This county has been about as fully populated as at present for nearly fifty years, the population in 1870 being only 800 less than that of 1910. The rich loess soil with originally a light growth of oak forest has been easily converted into farm land. The water power along Root River was also early made use of for flour mills.

Percentages of Classes of Land in Fillmore County

	Square miles	Per cent
Old drift, largely pebbly clay loam	172	19.81
Loess covered uplands and slopes	480	55.30
Rough stony land in rock bluffs	52	6.00
Bare slopes with residuary sand and clay and scattered drift pebbles	100	11.52
Valley bottoms with variable soil	64	7.37
	868	100.00

Farm and Crop Data for Fillmore County from Census of 1910

Rural population 17,784 or 20.5 per square mile

Per cent of land area in farms	93.4
Per cent of farm land improved	75.4
Average acres per farm	161.5
Average improved acres per farm	121.8
Value of all farm property	$36,250,145
Per cent of increase 1900 to 1910	78.1
Value of all crops in 1909	$3,926,257
Cereals (oats, corn, barley, wheat, rye)	$2,665,502
Other grains and seeds	$304,237
Hay and forage*	$659,683
Vegetables	$101,569
Fruits and nuts	$45,041
All other crops	$150,525

* Tame grass, 109,257 tons; wild grass, 3,389 tons.

MOWER COUNTY

Mower County, of which Austin is the county seat, is located on the southern border of the state, the third county from the Mississippi. The drainage of the west end of the county is southward by Cedar River into Iowa. The southeast part embraces the headwaters of upper Iowa River, whose course otherwise is in Iowa. The remainder of the county is drained eastward by Root River directly to the Mississippi. The divide between the Root River drainage and that of the Cedar and

Upper Iowa rivers embraces the highest land in southeastern Minnesota, its altitude being 1,350 to 1,420 feet above sea level. The altitude declines westward to only 1,200 to 1,250 feet along the border of Cedar River. But eastward an altitude of more than 1,300 feet is maintained to the eastern limits of the county.

The drift deposits are thick along the high divide just mentioned, the rock surface there being only up to about 1,300 feet above sea level. In the southeastern part of the county the rock surface reaches fully 1,350 feet. It is about 1,200 feet in the western part of the county. In the eastern part, sink holes in limestone abound, but in most of the county the drift deposits are so thick that such direct underground drainage is blocked and even preglacial valleys are completely filled.

From Cedar River eastward the drift is pre-Wisconsin and chiefly a compact clayey till with pebbly clay loam soil. Its surface has been leached of limestone pebbles to a depth of 4 to 6 feet. This drift has in places strips of gravel along the streams, which in some cases appear to have been exposed by the removal of the overlying till, for wells show the gravel to extend back beneath the till on the slopes and uplands. In a few places quartz pebbles derived from preglacial gravel beds form a notable constituent of the drift. This is especially the case in the southern and eastern parts of the county.

The latest or Wisconsin drift has its eastern limits along the western side of the county. In places a weak moraine marks the limits, but along much of the border there is merely a thin deposit of this young drift. There was a weak outwash into Cedar valley forming sandy plains in the northwest part of the county. The Wisconsin drift is chiefly clayey till with pebbly clay loam soil.

Percentages of Classes of Land in Mower County

	Square miles	Per cent
Old or pre-Wisconsin till, chiefly pebbly clay loam	595	83.68
Old gravel chiefly along valleys, gravelly loam	36	5.06
Wisconsin till, chiefly pebbly clay loam	26	3.66
Wisconsin gravel outwash and glacial drainage	42	5.91
Rock, bare or with very scant cover, chiefly along valleys	12	1.69
	711	100.00

Farm and Crop Data for Mower County from Census of 1910

Rural population 12,079 or 17 per square mile	
Per cent of land area in farms	94.1
Per cent of farm land improved	91.4
Average acres per farm	179.6
Average improved acres per farm	164.1
Value of all farm property	$31,290,093
Per cent of increase 1900 to 1910	54.3
Value of all crops in 1909	$3,231,403
Cereals (oats, corn, barley, wheat, rye)	$2,146,010

Farm and Crop Data for Mower County (Continued)

Other grains and seeds	$320,717
Hay and forage*	$526,517
Vegetables	$114,895
Fruits and nuts	$18,442
All other crops	$104,822

* Tame grass, 91,891 tons; wild grass, 9,582 tons.

FREEBORN COUNTY

Freeborn County is on the southern border of the state, with Albert Lea as the county seat. It includes 20 townships or 720 square miles, with a land area of 700 square miles, the remaining 20 square miles being occupied by lakes.[4] The greater part of the county is drained southeastward to Cedar River, but the northwest part drains northwestward to the Minnesota River. A few prominent points on moraines rise above 1,300 feet, but the general altitude is between 1,200 and 1,300 feet above sea level.

This county was covered by the latest or Wisconsin glaciation, except a few square miles in the southeast corner township. The border there, however, is not strongly marked, and exposures of the drift are so shallow that it is in places difficult to determine the full limits of the Wisconsin drift. The southeast corner of the county has the broad swales and somewhat mature erosion topography of the pre-Wisconsin drift.

The Wisconsin drift is very thin for from 4 to 8 miles back from its limits. There a strong moraine appears whose trend is slightly west of south across the eastern part of the county. There are several subsequent moraines of considerable strength traversing the county in the same general course. The city of Albert Lea lies between two such moraines, while another moraine passes east of Alden and Hartland. Two weak moraines cross the northwest part of the county, passing on each side of Freeborn Lake.

There are extensive marshes in the eastern part of the county between the first and second strong moraine, one lying southeast of Geneva Lake, having an extent of at least 30 square miles. This seems to have been once an expansion of Geneva Lake, and its surface stands only a few feet above the present lake level. There are other marshes inclosed between moraines in the northern part of the county and in till plains in the northwest part.

The lakes at Albert Lea once had an altitude 45 feet higher than now, and were combined into a single large glacial lake that covered much of the present site of the city. The brickworks in the west part of the city use clay deposits laid down in this expanded lake. The lowering of the lake was due to the cutting down of its outlet along Shell Rock River.

---

[4] The census of 1910 gives the county a land area of 735 square miles, which is evidently incorrect.

An extensive outwash plain of light sandy gravel lies immediately north and west of Albert Lea along the eastern border of a strong moraine. Another extensive outwash plain of sandy gravel connected with the same moraine, covers much of the southwest township of the county. There are also outwash plains connected with preceding moraines extending from the lakes to south of Glenville from which water discharged down Shell Rock valley.

The moraines are composed largely of clayey till, but they all include a few gravelly knolls, and some of them have local development of coarse stony drift with stony loam soil. The till plains, which with their included marshy tracts, occupy about half the surface of the county, have usually a very rich pebbly clay loam soil. The marshes and wet land on the till plain have been already greatly reduced by ditching.

Percentages of Classes of Land in Freeborn County

	Square miles	Per cent
Pre-Wisconsin till plain, black clay loam	20	2.86
Moraines of Wisconsin drift, chiefly pebbly clay loam soil	240	34.28
Outwash plains of sandy gravel with sandy to sandy loam soil	60	8.57
Till plains, chiefly pebbly clay loam	310	44.28
Lake clays with cultivable land	2	0.28
Marshes and bogs	68	9.70
	700	99.97

Farm and Crop Data for Freeborn County from Census of 1910

Rural population 14,588 or 20 per square mile

Per cent of land area in farms	87.9
Per cent of farm land improved	79.4
Average acres per farm	167.0
Average improved acres per farm	132.7
Value of all farm property	$27,961,397
Per cent of increase 1900 to 1910	60.6
Value of all crops in 1909	$3,074,017
Cereals (corn, oats, wheat, barley, rye)	$2,156,961
Other grains and seeds	$39,759
Hay and forage*	$603,961
Vegetables	$93,545
Fruits and nuts	$32,796
All other crops	$146,995

* Tame grass, 76,345 tons; wild grass, 64,550 tons.

FARIBAULT COUNTY

Faribault County is located on the southern border of the state with Blue Earth as the county seat. The drainage is all northward through Blue Earth River and its tributaries to the Minnesota River at Mankato.

The county is largely a till plain with an altitude above sea level of 1,050 feet on the north border and 1,150 to 1,200 feet near the state line. There are, however, weak moraines traversing it, and a very prominent moraine known as the Kiester Hills occupying much of the southeast township. The highest points on these hills are nearly 1,400 feet. There are also sharp knolls and clusters of knolls in the southwest part of the county rising 50 to 75 feet above the plain. Smaller gravel knolls occur 3 to 4 miles north of Bricelyn.

Northeast of Bricelyn there is an old lake bed covering several square miles in which the till is coated to a depth of several feet with sand and silt deposits. It occupies a low plain northwest of the Kiester Hills. Bars and beaches of sandy gravel are found on parts of its shore. This lake seems to have been drained by cutting down of the valley of East Fork of Blue Earth River. It may be remarked in this connection that the flattest parts of the Blue Earth basin seem likely to have been partially submerged for some time after the ice sheet disappeared, for the drainage development is likely to have been very slow.

The till plain has a black clay loam soil, but the moraines have a large amount of gravelly and stony loam, as also do the knolls scattered over the plain.

Percentages of Classes of Land in Faribault County

	Square miles	Per cent
Gravelly moraines and knolly drift, stony loam	25	3.47
Clayey moraine, pebbly clay loam	66	9.18
Till plain, chiefly black clay loam	600	83.45
Lake beds near Bricelyn, sandy and silty loam	18	2.50
Marshes and bogs including drained lakes	10	1.40
	719	100.00

Farm and Crop Data for Faribault County from Census of 1910

Rural population 11,684 or 16.2 per square mile	
Per cent of land area in farms	94.2
Per cent of farm land improved	88.6
Average acres per farm	202.7
Average improved acres per farm	179.6
Value of all farm property	$32,474,072
Per cent of increase 1900 to 1910	49.4
Value of all crops in 1909	$3,412,982
Cereals (corn, wheat, oats, barley, rye)	$2,775,679
Other grains and seeds	$24,188
Hay and forage*	$449,440
Vegetables	$80,674
Fruits and nuts	$32,360
All other crops	$50,641

* Tame grass, 32,509 tons; wild grass, 59,235 tons.

MARTIN COUNTY

Martin County is located on the southern border of the state, with Fairmont as the county seat. Its area, including lakes, is about 723 square miles. The lakes are estimated to cover 19 square miles.[5] The greater part of the county is drained eastward to Blue Earth River, but the southwest part is drained southward into Iowa by an eastern tributary of the Des Moines River. There are several chains of lakes in Martin County, which have been interpreted by Upham in his report on that county to mark the line of interglacial valleys, which have been irregularly filled by the deposits of the latest or Wisconsin till. The soil separating the Wisconsin till from the older till below it is to be seen in a few places along the bluffs of the lakes.

---

[5] The census of 1910 gives a land area of 719 square miles which is 15 square miles too high.

The surface slopes gently from southwest to northeast, being about 1,400 feet in the southwest corner, and about 1,050 feet in the northeast corner of the county.

Three morainic belts traverse the county from northwest to southeast, which were formed on the southwest side of the Minnesota valley lobe of the Keewatin ice field. They are all rather diffuse knolly tracts with nearly plane areas inclosed among the knolls and ridges. The middle belt, which traverses the central part of the county, is spread over a width of 4 to 8 miles, and the others are generally 2 to 4 miles wide. Gravelly knolls are scattered along the moraine, and occur to some extent along the bordering till plain, but the moraines are generally of clayey till. The plains have a rich black clay loam soil, though a small area northwest of Ceylon has a sandy soil.

Percentages of Classes of Land in Martin County

	Square miles	Per cent
Gravelly knolls in moraines and elsewhere, stony loam	30	4.26
Clay moraines with pebbly clay loam soil	175	24.86
Till plain with black clay loam soil	470	66.76
Gravelly and sandy soil on plains and valleys	20	2.84
Wet land, marshy and boggy	9	1.28
	704	100.00

Farm and Crop Data for Martin County from Census of 1910

Rural population 11,453 or 16.3 per square mile	
Per cent of land area in farms	93.0
Per cent of farm land improved	88.1
Average acres per farm	196.1
Average improved acres per farm	172.8
Value of all farm property	$30,512,250
Per cent of increase 1900 to 1910	87.8
Value of all crops in 1909	$3,155,826
Cereals (oats, corn, wheat, barley, rye)	$2,504,379
Other grains and seeds	$25,916
Hay and forage*	$458,496
Vegetables	$88,679
Fruits and nuts	$36,757
All other crops	$41,599

* Tame grass, 49,845 tons; wild grass, 49,541 tons.

JACKSON COUNTY

Jackson County, of which Jackson is the county seat, is located on the southern border of the state. The land area is 702 square miles and the lake area about 20 square miles. Heron Lake, a body of water 12 miles long, lies in the northwest quarter of the county. The drainage is largely by the Des Moines River, the outlet of Heron Lake being northward into the Des Moines. The east part of the county drains to the Minnesota River, while the southwest part is drained by Little Sioux River into the Missouri River drainage.

A prominent moraine on the west side of the Des Moines runs north to south across the county and rises in places above 1,500 feet. A similar altitude above sea level is attained in the extreme southwest part of the county which is crossed by another moraine. There are two weak moraines east of the Des Moines, separated by a till plain about 6 miles wide. A more extensive till plain covers the western part of the county. The moraines are very largely of clayey till. The till plains have a rich black clay loam soil, and portions of the plains in the western part of the county have a thin deposit of silt over the till.

A narrow gravelly strip follows the Des Moines valley for a few miles below Windom, but in the southern part of the county the Des Moines valley has bluffs of till to a height of nearly 100 feet above the stream.

Percentages of Classes of Land in Jackson County

	Square miles	Per cent
Moraines chiefly of clayey till, pebbly clay loam	260	37.04
Gravelly morainic drift with stony loam soil	10	1.42
Gravel in Des Moines valley	17	2.42
Till plain, black clay loam	405	57.69
Marshes and bogs	10	1.42
	702	99.99

Farm and Crop Data for Jackson County from Census of 1910

Rural population 10,539 or 15 per square mile	
Per cent of land area in farms	91.6
Per cent of farm land improved	86.2
Average acres per farm	215.8
Average improved acres per farm	186.1
Value of all farm property	$26,357,716
Per cent of increase 1900 to 1910	86.4
Value of all crops in 1909	$2,750,726
Cereals (corn, oats, barley, wheat, rye)	$2,163,845
Other grains and seeds	$92,197
Hay and forage*	$392,087
Vegetables	$73,214
Fruits and nuts	$19,574
All other crops	$9,809

* Tame grass, 48,787 tons; wild grass, 46,386 tons.

NOBLES COUNTY

Nobles County is located on the south border of the state in southwestern Minnesota, with Worthington as the county seat. The drainage of the northeast part is to the Des Moines River, but the southern and western parts drain southwestward across Iowa into the Big Sioux River, and thence to the Missouri.

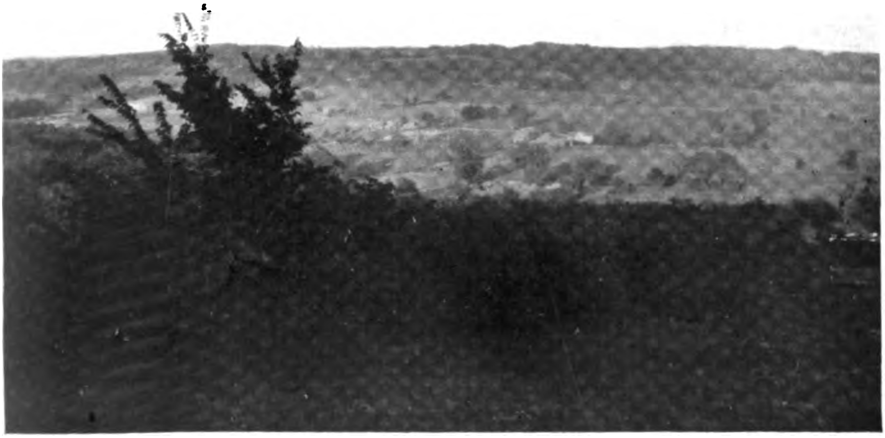
The county is crossed from northwest to southeast by the Coteau des Prairies, its crest passing between Worthington and Rushmore. Much of the crest stands above 1,700 feet, and part of it above 1,750 feet, but its altitude at the state line is 1,650 feet above sea level. There is a gentle slope southwestward from the crest to about 1,450 feet in the southwest corner of the county. There is a similar slope to the northeast corner of the county, which also is about 1,450 feet.

Two well-defined moraines which are separated by a narrow till plain 1 to 5 miles in width, traverse the high part of the Coteau des Prairies across the county. To the east of the eastern or inner moraine is a smooth till plain extending beyond the county limits into Jackson County. To the west of the western moraine a tract of very thin young or Wisconsin drift is found. The drift veneers the eroded surface of an older drift and the present drainage runs in about the same lines as that the interglacial valleys followed.

The pre-Wisconsin or old gray drift, which is exposed in a narrow strip on the southwest edge of the county, contains there a large amount of gravel, and has a thin coating of silt some of which may be wind deposited. A more typical deposit of silt or loess sets in a few miles farther west. The gravel in this old drift is much stained by iron and much more weathered in appearance than the Wisconsin drift. In places within the limits of the Wisconsin drift the old gravel has been gathered up and mixed with the fresh material of that drift. Good exposures of such an admixture are to be seen in Adrian and westward between the village and Kanaranzi Creek. The older till, though more deeply oxidized than the Wisconsin drift, shows only a slight depth of leaching of its calcareous material. A response with acid is usually obtained within two feet of the surface, whereas in drift of similar age in the southeast part of the state there has been leaching to a depth of 4 to 6 feet. The deficiency in rainfall is thought to be the main cause for the slight amount of leaching, as was noted in the general discussion.

The moraines of Wisconsin drift are composed largely of clayey till, but parts of them are of coarse material with a slight loamy admixture, and there are also gravelly knolls. The till plains are of clayey character, and in places have a coating of fine silt loam a few inches thick above the pebbly till.

There are narrow strips of gravelly outwash connected with parts of the border of the prominent moraines of this county. The valleys also that lead southwest from the Coteau des Prairies generally are fringed with narrow gravelly strips. These seem to have been formed in part by glacial drainage, but are being worked over and redeposited by modern drainage lines.



A. ZUMBRO VALLEY NEAR ROCHESTER

B. VALLEY OF ROLLINGSTONE RIVER NEAR MINNESOTA CITY

C. MISSISSIPPI VALLEY AT MINNESOTA CITY

UNIV. OF MIC

Percentages of Classes of Land in Nobles County

	Square miles	Per cent
Old or pre-Wisconsin drift, largely gravelly to stony loam	66	9.14
Moraines of Wisconsin drift, chiefly pebbly clayey loam	120	16.62
Wisconsin till plain, largely black clay loam	500	69.25
Outwash and valley gravels, gravelly to stony loam	36	4.99
	722	100.00

Farm and Crop Data for Nobles County from Census of 1910

Rural population 9,358 or 13 per square mile	
Per cent of land area in farms	90.5
Per cent of farm land improved	92.8
Average acres per farm	229.9
Average improved acres per farm	213.4
Value of all farm property	$30,066,799
Per cent of increase 1900 to 1910	106.1
Value of all crops in 1909	$2,788,111
Cereals (oats, corn, barley, wheat, rye)	$2,149,629
Other grains and seeds	$85,392
Hay and forage*	$436,346
Vegetables	$93,096
Fruits and nuts	$18,312
All other crops	$5,336

* Tame grass, 56,284 tons; wild grass, 29,809 tons.

ROCK COUNTY

Rock County is the southwest corner county of the state, with Luverne as the county seat. The drainage is all southwestward to Big Sioux River. The highest land is a quartzite ridge that runs from near Luverne northward past Hardwick to Trosky, and which stands 1,650 to 1,750 feet above sea level. The lowest land in the southwest part of the county is about 1,400 feet, but on the divide between the streams an altitude of 1,500 feet is maintained nearly to the southern end of the county.

The Wisconsin or young gray drift covers only a few square miles in the northeast township, and there it is a thin veneer on the eroded surface of the old gray till. In places it has a slight ridge at the border, such being the case for two or three miles from the north line of the county on the west bluff of Rock River, but usually the drift is only 10 to 20 feet thick. There appears to have been a weak outwash from it down the tributaries of Rock River, as well as along Rock River itself.

The old gray drift contains a large amount of gravelly material, but till is interbedded with the gravel and forms part of the surface.

The southwest part of the county has a deposit of loess over the till several feet in depth, or enough to form the soil and subsoil. Elsewhere the cover of silt is thin and discontinuous.

The eastern part of the county east of Rock River has a heavy drift deposit, but the northwest quarter is very thinly coated with drift, and small outcrops of quartzite are numerous. The old till of this county, like that of Nobles County, is not deeply leached, but it shows high oxidation, and has been greatly eroded in its thick portions.

Percentages of Classes of Land in Rock County

	Square miles	Per cent
Old drift with scanty silt cover, soil chiefly a sandy to gravelly loam	250	50.81
Loess over old drift, silt loam	170	34.55
Nearly bare rock in old drift area	30	6.10
Wisconsin till sheet, pebbly clay loam	18	3.66
Wisconsin glacial drainage	24	4.88
	492	100.00

Farm and Crop Data for Rock County from Census of 1910

Rural population 6,495 or 13 per square mile

Per cent of land area in farms	91.6
Per cent of farm land improved	93.9
Average acres per farm	239.3
Average improved acres per farm	224.7
Value of all farm property	$25,297,625
Per cent of increase 1900 to 1910	136.3
Value of all crops in 1909	$2,463,846
Cereals (corn, oats, barley, wheat, rye)	$2,043,051
Other grains and seeds	$11,516
Hay and forage*	$315,685
Vegetables	$81,350
Fruits and nuts	$7,417
All other crops	$4,827

* Tame grass, 38,791 tons; wild grass, 23,070 tons.

INDEX

Page
Adrian, glacial drift near............... 140
Afton, glacial drift near................ 89
Agassiz, Lake....5, 12, 14, 16, 17, 18, 19, 56, 57, 58, 72, 73, 74, 76, 77, 79, 88, 97, 98, 107, 111, 112, 130, 131
Agricultural development since 1850.....58-60
Agriculture, Department of, University of Minnesota 4
Aitken County.........9, 12, 17, 49, 50, 64-65
Aitken, glacial Lake.................... 17
Albert Lea, glacial formations near...135, 136
Alden, glacial moraine near............. 135
Alexandria 72
Alluvial bottoms 58
Altitude of Minnesota................... 6
  map 8
Altitude of south half of Minnesota...... 45
Amboy, glacial formations near......... 123
Annandale, outwash plains near......... 55
Anoka 82, 86
Anoka County 9, 53, 60, 86-87
Appleton, glaciation near................ 55
Area of Minnesota.................... 5
Arthyde 65
Austin 133
  limestone near 21
Barley 60, 108
Battle Lake, outwash plain near......... 72
Beardsley, moraine near................ 77
Beaver dams 63
Becker County 6, 9
  crop-growing season 31
Belle Plaine prairie..................... 104
Benton County 49, 50, 82-83
Benton, Lake 116, 118
Beroun, swamps near.................. 63
Big Sioux River.......116, 117, 119, 139, 141
Big Stone County...................57, 77-78
Big Stone Lake..........10, 57, 58, 76, 77
Blue Earth 136
Blue Earth County................55, 122-24
Blue Earth River....................136, 137
Bois des Sioux River..........57, 74, 75, 76
Braham, glaciation near................ 65
Brainerd, glaciation near...............17, 67
Bricelyn, glacial lake features near...... 137
Brown County 55, 113-14
Brown Valley, glacial lake features near.. 16
Bruno, swamps near.................. 63
Buffalo 92
Butters, Frederic K., map prepared by... 20
Caledonia, loess near.................. 131
Cambridge 85
Cannon River 105, 106, 107, 109, 111, 123, 124, 125
Carlton County 14, 16
Carrington loam 107, 109, 110
Carver County 49, 53, 55, 60, 102-3

Page
Cass County 9, 50, 68
  glacial lake features................ 16
Cedar River 125, 126, 133, 134, 135
Center City 87
Cereals, acreage 60
Chanarambrie Creek 119
Chandler, glacial features near.........52, 119
Chaska 102
Chippewa County 55, 97
Chippewa River 57, 72, 73, 78, 79, 80, 96
Chisago County 9, 53, 58, 87-88
Christina Lake 72
Classification of land. *See* Land Classification
Clear Lake, moraine near.............. 112
Clearwater County 9
  crop-growing season 31
Clearwater River 7, 55
Climate, continental 23-24
Climatic conditions of Minnesota........23-44
Cold Spring, moraine near............51, 81
Cook County 6
Corn 60
Cortland, moraine near................. 112
Coteau des Prairies........6, 52, 98, 115, 116, 117, 118, 119, 120, 140
Cottonwood County 52, 55, 120-21
Cottonwood River 113, 114, 115
Cretaceous deposits 115
Crookston, glacial lake features near...... 16
Crop-growing season.................... 3
  length 31, 34
  temperature 26
Crow River......55, 80, 81, 93, 95, 100, 101, 102
Crow Wing County.....................67-68
  glacial lake features................ 17
Crow Wing River...............16, 68, 70, 72
Dakota County.............12, 47, 49, 104-106
Darling Station, esker near............. 69
Darwin, outwash plain near...........55, 93
Deerhorn Creek........................ 74
Des Moines lobe....................... 101
Des Moines River.......119, 120, 121, 138, 139
Dodge County 15, 46, 47, 126-27
  agricultural conditions.............. 60
Douglas County...............51, 54, 55, 72-73
Drainage, dendritic..................... 106
Drainage, importance.................. 18
Drainage of Minnesota................. 6-7
Drainage of south half of Minnesota...... 45
Drift 9, 12, 14, 53-142
  Illinoian 48-49
  Iowan 47-48
  Kansan 47, 48-49
  Labradorian 50
  old gray.......................... 47
  old red...........................48-49
  Patrician 49-50
  pre-Wisconsin 46-47

Page
Drift (continued)
  Wisconsin red........................49-50
  young gray..........................50-52
  young red...........................49-50
Driftless area.................2, 10, 18, 45-46
Duluth, settlement.......................59-60
Duluth, Lake.................14, 16, 17, 63, 88
Duluth, rainy days...................... 41
Dune sands.........53-54, 69, 83, 84, 85, 86, 88
Eden Valley, moraines near..............54, 55
Elbow Lake.............................. 73
Elk River...............................82, 84
Elysian, glacial features near..........111, 123
Elysian, Lake........................... 124
Embarrass River, glacial features near.... 16
Erosion 47
  in prairie and forest................. 19
Eskers 49, 69, 83
Fairmont 137
Fargo loam 110, 123
Faribault 109
Faribault County..................55, 136-37
Farmington, loess deposit near.......... 106
Feldspar, weathering.................... 19
Fergus Falls............................ 71
Fillmore County.................15, 46, 132-33
Fires, forest
  effect on soil......................21-22
  Hinckley fire.......................22, 63
Foley, esker near....................... 83
Forest and prairie, map showing......... 20
Forest City, glacial lake formation..... 94
Forest fires. *See* Fires
Forested areas, settlement.............. 60
Fort Ripley, dune sand near............. 69
Foxhome, soil near...................... 75
Freeborn County 53, 60, 135-36
Freeborn Lake........................... 135
Fremont, soil near...................... 130
Frosts, killing, average date of first and
  last 31, 32, 33
Fruit-growing 89
Gaylord 101
Geneva Lake............................. 135
Geological Survey. *See* Minnesota Geological Survey and United States Geological Survey
Geology, surface.........................10-18
Glacial deposits........................ 12
  See also Drift
Glacial lakes...........................16-18
Glencoe 101
Glenville, outwash plain near........... 136
Glenwood 79
Goodhue County........15, 46, 47, 49, 60, 106-9
Granger, quartz formations near......... 132
Granite Falls, formations near.......... 97
Granite outcrops................83, 97, 98, 100
Grant County......................57, 73-74
Grantsburg lobe ....
  53, 54, 55, 65, 81, 84, 85, 87, 92, 101

Page
Gray Eagle, moraines near............... 70
Green Lake, moraines near............... 95
Hadley, moraine near.................... 119
Hampton, red drift near................. 105
Hanley Falls, drainage near............. 56
Hardwick, quartzite ridge............... 141
Harris 87
Hartland, moraines near................. 135
Hastings 104
Hay 60, 89
Hennepin County.....9, 49, 53, 55, 58, 60, 91-92
Heron Lake..............................138-39
Hinckley forest fire....................22, 63
Houston County...........2, 12, 46, 60, 131-32
Hubbard County.......................... 9
  crop-growing season................... 31
  glacial features...................... 16
Hudson Bay drainage system.............. 6-7
Humidity, mean relative................. 43
Huron, glacial lake..................... 17
Illinoian drift.........................48-49
Improved land........................... 61
Interglacial valleys...66, 69, 71, 74, 78, 79, 83, 119
Iowan drift.............................47-48
Isanti County....................9, 53, 85-86
Itasca County...........................9, 16
Jackson County...............52, 121, 138-39
Kanabec County......................49, 65-66
Kanaranzi Creek......................... 140
Kandiyohi County..........54, 55, 80, 94, 95-96
  highest temperature in................ 26
Kansan drift........................46-47, 105
Keewatin ice sheet......9, 12, 15, 17, 49, 53-142
Kettle River............................50, 63
Kiester Hills..........................136, 137
Kimball, moraines near..............54, 55, 81
Kingston, glacial lake features near.....55, 94
Klossner, moraines near................. 112
Knox silt............................... 107
Koochiching County 16, 22
Labrador ice sheet..................15, 49, 50
Lac qui Parle........................... 58
Lac qui Parle County....................55, 98
Lac qui Parle River..................... 98
Lake City, glacial drift near............ 128
Lake deposits 14
Lake of the Woods........................5, 16
Lakeland, glacial deposits near......... 58
Lakes, glacial 16-18
Lakes of Minnesota...................... 15
  area 7
Land classification 53-142
Leaching 19, 46, 105, 107, 132, 134, 140
Leaf Hills..............................6, 72
Leaf Mountain 72
Leech Lake 7
Leech Lake Dam, climate.................26, 40
Le Sueur Center......................... 111
Le Sueur County....................53, 111-12
Le Sueur River.......................... 124
Limestone, leaching. *See* Leaching

Page

Lime as fertilizer........................ 21
Lime, occurrence in Minnesota.........10, 21
Lincoln County 51, 52, 60, 116-17
Litchfield, glacial deposits near.........55, 93
Little Cottonwood River.................. 113
Little Falls 68, 69
Little Fork River basin..................16, 22
Little Sioux River....................... 139
Loess...............2, 10, 11, 13, 18, 46, 47, 59, 106, 107, 108, 109, 126, 127, 128, 130, 131, 133, 140, 141
Long Prairie, glacial deposits near......17, 70
Long Prairie River.....................70, 72
Louisburg 98
Luverne, quartzite ridge................. 141
Lynd, climate 40, 41
Lyon County 52, 55, 115-16
McGregor, sand deposits near............ 12
McLeod County 54, 55, 101
Madison 98
Mahnomen County, crop-growing season.. 31
Manannah, outwash plain................. 55
Mankato, geologic formations near..21, 55, 122
Mantorville 126
Marsh Lake 58
Marshall, moraines near.............115, 116
Marshall loam 107, 109, 123
Marshes 87, 91, 99, 112, 122, 125, 135, 136
Martin County 55, 137-38
Matrix 12
Meeker County 55, 81, 93-94, 95
Mesabi Iron Range
  climate 31, 40
  geologic features 6, 9, 15, 16
Mesas 105, 109
Mexico, Gulf of, drainage system......... 6-7
Mille Lacs 7, 15, 49, 50, 65
Mille Lacs County..................65, 66-67
Mille Lacs moraine...................... 67
Minneapolis
  limestone formations near............ 21
  sandy soil near.....................54, 91
Minnehaha Falls 91
Minnesota Geological Survey...........3-4, 47
Minnesota lobe 55
Minnesota River................14, 55-59, 78, 97, 102, 104, 111-116, 122-25
Minnetonka, Lake 7, 91
Minnewaska, Lake 80
Missouri River 116, 139
Mora 65
Moraines 5, 7, 49, 51, 52, 142
  central Minnesota 54-55
  Mississippi valley 56
  Red River plain...................... 57
  southeastern Minnesota 53
  southwestern Minnesota 52-53
Morris 78
Morrison County 16, 49, 50, 68-70
Motley, esker near...................... 69
Mower County 15, 47, 133-35
Murray County 52, 119-20

Page

Muskegs 19
Mustinka River 57, 73, 75, 76, 77
Nashua, soil near....................... 75
Nerstrand, loess deposits............... 109
New London, moraines near.............. 54
New Munich, moraines near............51, 81
New Ulm, granite outcrops near...10, 112, 113
Nicollet County 55, 112-13
Nobles County 46, 52, 139-41
Norcross beach 76
North Crow River....................... 55
Northfield, moraines near............... 109
Northwest Angle 5
Oats 60, 62
Odessa, glacial deposits.................77, 78
Olivia 100
Olmsted County 15, 46, 60, 126, 127-28
Ortonville 77
Osakis Lake 70
Ostrander, quartz pebbles............... 132
Otter Tail County.......6, 51, 54, 55, 57, 71-72
Otter Tail Lake......................... 72
Otter Tail River.......................71, 74
Outwash plains...5, 50, 55, 57-58, 72, 77, 78, 80, 86, 90, 91, 103, 113, 125, 136
Owatonna 125
Paleozoic limestone 107
Parkers Prairie Plain................... 72
Patrician ice sheet.....15, 16, 49-50, 53, 63, 65
Paynesville 54
Peat 3
Pepin, Lake 107, 128
Pillager, glacial lake features near......16, 17
Pine County 22, 49, 50, 53, 58, 63-64
Pipestone City, glacial drift near......... 118
Pipestone County 15, 46, 52, 117-19
Pokegama Falls, lowest temperature....... 26
Polk County 16
Pomme de Terre River..........73, 78, 79, 96
Pope County 54, 55, 79-81
Posey, C. J., acknowledgment to......... 4
Prairie and forest, map showing.......... 20
Prairie, settlement 60
Precipitation 43
  average annual 35, 36
Prinsburg, moraine near................. 95
Pursell, U. G., acknowledgments to...... 4
Pursell, U. G., chapter by.............23-44
Quartz 132, 134
Quartzite 10, 118, 120, 141
Rabbit Creek 74
Railroad building 59-60
Rainfall of south half of Minnesota...... 45
Rainy days, number...................... 41
Ralph, G. A., referred to........69, 70, 83, 85
Ramsey County 49, 89-90
Raymond 95
Red Lake, area.......................... 7
  glacial lake features near........... 16
Red Lake County......................... 7
Red Lake River.......................... 7
Red River plain.......................56-57

Page
Red River....6, 7, 9, 14, 18, 71, 73, 75, 76, 77, 78
Red Wing, altitude....106, 107
Redwood County....55, 114-15
Redwood Falls, granite outcrops near.... 115
Redwood River 56, 114-15
Relief of Minnesota.... 6
Renville County 55, 95, 100
Residuary material 11
Rice County 47, 53, 109-11
Rochester 127
Rock County 15, 46, 52, 118, 141-42
Ronneby, esker near.... 83
Root River 126, 127, 131, 132, 133
Round Prairie, gravel plains near.... 70
Royalton, dune sand near.... 69
Rum River....65, 66, 82, 84, 85
Russell, gravel knolls near.... 116
Rye 60
St. Anthony Falls.... 91
St. Charles, loess near.... 130
St. Cloud, red drift near.... 81
St. Croix River....7, 12, 17, 50, 53, 58, 63, 81, 87
St. Croix, Lake.... 58
St. Francis River.... 84
St. James, soil near.... 122
St. Lawrence, Gulf of, drainage system.... 6-7
St. Louis County....16, 22
St. Louis River....7, 9, 11, 15
St. Paul 54, 89, 90
St. Peter, glacial drift near.... 112
St. Peter sandstone.... 109
Sand dunes 53, 54, 69, 83, 86
Sand, wind-blown 11
Sandstone outcrops 10
Sauk Center, moraine near.... 51
Sauk Rapids, granite outcrops near.... 83
Sauk River 51, 55, 70, 80, 81, 93
Savage, dune sand near.... 104
Sawtooth Range 6
Scott County 49, 58, 103-4
Settlement of Minnesota....
....59-60, 104-5, 106, 129, 133
Shakopee prairie 104
Sherburne County 53, 60, 82, 84-85
Shetek, Lake 120
Sibley County 55, 101-2
Sink holes 134
Sioux loam 111
Sioux River 117
Slayton 119
Snake River 65
Snowfall 40, 41
Soil
  See also Land classification
  central Minnesota 55
  definition 1
  Minnesota 18-22
  outwash plains....57-58
  southeastern Minnesota 53, 54
  southwestern Minnesota 53
  survey 58

Page
Soils, Bureau of, referred to....
....107, 108, 109, 110, 123
Soils, Division of, University of Minnesota 4
South Haven, outwash plains near.... 55
Stearns County 49, 51, 55, 80, 81-82, 94, 95
Steele County 53, 125-26
Stevens County 57, 78-79
Stillwater 21, 58, 88
Straight River 125
Striations, glacial 47
Sturgeon Lake 50
Sunrise River 87
Superior, Lake 6, 7, 14, 15
  influence on climate....23, 31, 44
Superior lobe 50, 63, 65
Survey, soil ....
  See Soil Survey and Land classification
Swamps 3, 63, 64-65, 75, 93, 94
  drainage 7, 60
Swan River 70
Swift County 54, 55, 57, 79, 96-97
Temperatures
  average seasonal 31
  highest known 26, 29
  mean annual 25
  mean January 26, 27
  mean July 26, 28
  monthly and annual mean.... 26
Till plains 5, 12, 18, 53, 63-142
Tintah, swamps near.... 75
Tintah beach 76
Todd County 16, 49, 50, 51, 70-71, 73
Topeka, eskers near.... 69
Topography of Minnesota.... 5
Traverse County 57, 75-77
Traverse, Lake 16, 73, 75, 76
Trosky 141
Truck gardening 92
United States Bureau of Soils.... 4
United States Geological Survey.... 3-4
United States Weather Bureau....4, 24
Upham, glacial Lake.... 17
Upham, Warren, referred to....4, 17, 20, 52, 138
Upper Iowa River....131, 132, 133, 134
Vermilion Iron Range, crop-growing season 31
Vermilion River 103, 105
Wabash silt loam.... 108
Wabasha 128
Wabasha County 15, 46, 60, 128-29
Wadena County 16, 50, 51
Wadena, glacial Lake.... 16
Waseca County 53, 124-25
Washington County 49, 88-89
Watab, granite outcrops.... 83
Watkins, young gray drift.... 54
Watonwan County 55, 56, 121-22
Watonwan River 113, 121, 123
Waukesha loam 108

Page
Weather Bureau. *See* United States Weather Bureau
Weathering 19
West Rum River.......................... 83
Wheat 59, 60, 108
Wheaton 75
White Bear Lake.......................... 88
Whitewater River 127
Wilkin County 57, 74-75
Willmar County 95
Winchell, N. H., referred to............4, 17
Windom 120, 139
Winds, prevailing 40, 42
Wind deposits 11-12

Page
Winnibigoshish, Lake 7
Winona County 2, 12, 15, 46, 129-31
Wisconsin drift...51, 63-64, 66, 69, 70, 71, 88, 106, 108, 109, 118, 119, 126, 131, 134, 135, 138, 140, 141
Worthington 139, 140
Wright County....9, 49, 53, 54, 55, 60, 92-93, 94
Yellow Bank River...................... 98
Yellow Medicine County.........52, 55, 56, 99
Yellow Medicine River.................. 56
Zumbro River 106, 107, 109, 125, 126, 127, 128, 129
Zumbrota, glacial drift near............ 107

The University of Minnesota

MINNESOTA GEOLOGICAL SURVEY

WILLIAM H. EMMONS, DIRECTOR

IN COÖPERATION WITH THE UNITED STATES GEOLOGICAL SURVEY

BULLETIN NO. 15

PRELIMINARY REPORT ON THE GEOLOGY OF EAST CENTRAL MINNESOTA INCLUDING THE CUYUNA IRON-ORE DISTRICT

BY

E. C. HARDER

AND

A. W. JOHNSTON

MINNEAPOLIS
The University of Minnesota
1918

CONTENTS

Introduction 1
  Acknowledgment 2
Terminology 2
General geology of Minnesota 4-15
Rocks of east central Minnesota 15-94
  Previous geologic work 15
  General distribution and lithology of the rocks 23
  Descriptions of rock outcrops 30
    Outcrops of silicic igneous rocks 30
      Southern Cass, Todd, and western Stearns counties 30
      Morrison County 32
      Stearns, Benton, Sherburne, and western Mille Lacs counties 38
      Northern Mille Lacs, Kanabec, southern Aitkin, and western Pine counties 40
    Outcrops of subsilicic igneous rocks 49
      Todd County 49
      Morrison, Benton, and Stearns counties 50
      Aitkin, Carlton, and Pine counties 52
    Outcrops of slate, schist, and other metamorphic rocks 58
      Morrison and Benton counties 58
      Crow Wing, Cass, and Aitkin counties 63
      Pine, Carlton, and southern St. Louis counties 65
    Outcrops of sandstone and other clastic rocks 90
      Keweenawan sandstone and related rocks 90
      Cretaceous sediments 93
The Cuyuna iron-ore district 94-135
  Location of the district 94
  History of the district 96
  General geology of the district 107
    General statement 107
    Structure of the rocks 111
    Lithology of the rocks 112
      Older metamorphosed rocks (Virginia slate) 112
      Later intrusive rocks 123
      Later volcanic and sedimentary rocks 124
    Occurrence of the iron-bearing rocks and iron ore 124
      Distribution of iron-bearing rocks and ore 124
      Occurrence and character of ore 129

Geology of the principal mines....135-168
North range mines.... 135
Ferro mine.... 135
Joan No. 3 mine.... 137
Algoma mine 137
Rowe mine.... 139
Hillcrest mine.... 141
Pennington mine.... 142
Armour No. 1 mine.... 144
Ironton mine.... 146
Armour No. 2 mine.... 146
Thompson mine.... 148
Meacham mine.... 150
Croft mine.... 150
Cuyuna–Mille Lacs mine.... 152
Mangan No. 1 mine.... 154
Sultana mine.... 154
Hopkins mine.... 156
Joan mine.... 157
Mahnomen mine.... 157
Mangan No. 2 mine.... 159
Kennedy mine.... 159
South range mines.... 162
Adams mine.... 162
Hobart exploration shaft.... 163
Wilcox mine.... 164
Brainerd-Cuyuna mine.... 166
Barrows mine.... 166
Bibliography 169

LIST OF ILLUSTRATIONS

Plate I. Relief map of the Lake Superior district showing the location of the iron-ore districts.............. 10
II. Map of east central Minnesota showing the location of rock outcrops..........................in pocket
III. A. Granite outcrop at Meyers Quarry near Pierz, Morrison County, showing horizontal jointing
B. Inclusions of dark gray granite in pink granite at Gravelville, Morrison County.............. 34
IV. A. Granite exposures on Rum River, south of Onamia, Mille Lacs County
B. Granite exposures along Hay Creek, a branch of Snake River, Kanabec County.............. 40
V. A. Granite and mica schist outcrops at Lower Falls on Snake River, Kanabec County
B. Granite exposures at Upper Falls on Snake River, Kanabec County.............................. 44
VI. A. Outcrop of chloritic schist near the station at Randall, Morrison County
B. Chloritic schist outcrops at Randall showing cleavage.................................. 58
VII. A. Slate and phyllite outcrops on Mill Island at Little Falls, Morrison County
B. Slate outcrop at Little Falls showing relation of cleavage to bedding.......................... 60
VIII. A. Outcrop of slate and phyllite on Split Rock River, southwestern Carlton County, showing horizontal schistosity
B. Outcrop of slate and phyllite along the railway northeast of Denham, Pine County, showing parallel jointing.......................... 66
IX. A. Outcrops of slate along St. Louis River below Thomson Dam, Carlton County
B. Outcrops of slate at the northern Pacific Railroad bridge over St. Louis River below Thomson Dam, Carlton County...................... 86
X. A. Calcareous concretions weathering out of slate at Carlton
B. Small dike of diabase intruding slate at Carlton.. 89

XI. Map of the principal part of the Cuyuna iron-ore district showing distribution of known iron-bearing rocks and lines of maximum magnetic attraction ....in pocket
XII. A. Exploration by drilling in the Cuyuna district
B. Starting excavation with steam shovel at the Mahnomen open-pit mine, near Ironton...... 96
XIII. A. Removing overburden by hydraulic method at the Rowe mine, near Riverton
B. Removing overburden by hydraulic method at the Hillcrest mine, near Ironton................ 100
XIV. A. Sinking a concrete shaft at the Croft mine, near Crosby
B. Iron-ore concentrating plant at the Rowe mine, near Riverton............................ 102
XV. A. Pennington–Armour No. 1 open-pit mine near Ironton
B. Head-frame and trestle of Cuyuna–Mille Lacs mine, near Ironton........................ 104
XVI. A. Head-frame, concentrating plant, and part of open pit at Thompson mine, near Crosby
B. Head-frame and power house of Adams mine, near Deerwood............................ 106
XVII. A. Ferruginous chert showing regular interbanding of chert and iron oxide
B. Ferruginous chert showing irregular intermixing of chert and iron oxide.................... 114
XVIII. A. Wash ore showing porosity due to disintegration and removal of chert
B. Minor plications in the iron-bearing rocks at the west end of the Rowe open pit............. 118
XIX. Types of ore deposits in the Cuyuna iron-ore district 138
XX. Map and sections showing the geology and workings of the Rowe mine.....................in pocket
XXI. Map and sections showing the geology and workings of the Pennington, Armour No. 1, and Armour No. 2 mines..........................in pocket
XXII. Map and sections showing the geology and workings of the Thompson mine..................in pocket

PRELIMINARY REPORT ON THE GEOLOGY OF EAST CENTRAL MINNESOTA INCLUDING THE CUYUNA IRON-ORE DISTRICT

By E. C. Harder and A. W. Johnston

INTRODUCTION

The geologic work in the Cuyuna iron-ore district is being done jointly by the Minnesota Geological Survey and the United States Geological Survey. Since only a few outcrops of bed rock occur in the district or in the region adjacent to it, the study has been based largely on the results of exploration and mining work. Many drill cores and records of diamond drilling from various parts of the district have been examined, and in addition the occurrence and structure of the rocks as shown in the underground and open pit workings of various mines have been studied in detail, and detailed geologic and topographic maps have been made of several of the open pit mines.

In order to gain a more comprehensive idea of the major structure of the rocks of east central Minnesota, and particularly to note if possible the relation of the rocks of the Cuyuna district to such major structure, a careful study of the rock outcrops of the region lying west, south, and east of the Cuyuna district was made. This included the detailed mapping of most of the rock exposures lying nearest to the Cuyuna district in Cass, Todd, Morrison, Mille Lacs, Kanabec, Pine, Carlton, and Aitkin counties, and a more general study of the outlying exposures in these counties and also in Stearns, Benton, and Sherburne counties. North of the Cuyuna district, in the region lying between it and the Mesabi district, no rock outcrops are known and the relation between the rock formations of these two districts will have to be determined by underground exploration.

As the development work in the Cuyuna district is constantly in progress, it has been considered advisable to publish the present preliminary report giving the general results of the investigations up to the present and to delay the publication of a more complete report pending the accumulation and study of further data.

The present report is incomplete in many ways. The descriptions of the rock outcrops are very general. Thin sections for microscopic examination of many of the rocks have not yet been made, and the exact mineral composition of these remains to be determined. In the descriptions, therefore, only the general characters and geologic relations of the rocks are discussed, the details of texture and mineral composition being only briefly mentioned.

The structure and stratigraphy of the rocks of the Cuyuna district also remain to be determined. Information is as yet too incomplete to attempt arranging the various beds into a stratigraphic succession. It is a question even whether it will be possible to work out such a succession for many years to come because of the general similarity of the rocks and the complex deformation which they have suffered. As regards the structure of the rocks more data are available and it is hoped that some progress may be made in this respect before the publication of the final report.

The origin of the iron ore is only briefly mentioned, a more complete discussion being reserved for the final report.

Accompanying the present report is a map showing the trend and location of the different belts of iron-bearing formation in the Cuyuna district. This is the first map which has been published giving in detail the surface distribution of the iron-bearing formation in the Cuyuna district, and it should be realized that the information on it is as yet far from complete. Doubtless this map will have to be revised, and the only reason for publishing it at the present time is the hope that it may assist in the exploration work which in this district is being conducted under many difficulties.

ACKNOWLEDGMENT

In the preparation of this report on the Cuyuna district the writers have had to depend very largely on the generosity of the exploration and mining companies in furnishing information and in allowing access to their records and files. Almost without exception the information has been willingly furnished and permission to examine drill cores, maps, and reports has been cheerfully given. In many instances companies and individuals have gone to considerable expense in furnishing blue prints and other materials to aid in the preparation of the report. For this coöperation the writers wish to express their sincere thanks.

The writers are indebted to L. G. Ravicz, W. B. Lang, and E. A. Sweetman for assistance in the field.

TERMINOLOGY

The pre-Cambrian rocks of the Lake Superior region include a number of rather uncommon lithological types. These have received distinctive names which are in fairly general use throughout the region. Below are given brief explanations of some of the less well-known rock terms used in this paper as well as of more general rock terms whose usage in this paper has been restricted to certain definite types of rock.

Iron-bearing formation is a term intended to include all the various ferruginous rocks which make up the iron-bearing beds, original as well as altered.

Cherty iron carbonate or cherty siderite is a light to dark-colored, dense, fine-grained rock, usually banded and consisting of interlayered and intermixed chert and siderite. When much argillaceous material occurs in it, the term slaty or argillaceous iron carbonate is used. The iron in most of the iron-bearing formations of the Lake Superior region was probably originally deposited as carbonate.

Greenalite rock is a dark green, granular, ferrous silicate rock occurring in the Mesabi district. Greenalite is believed to be the original rock from which the ferruginous chert and ore of the Mesabi district are derived.

The term ferrous rock includes both ferrous carbonate and ferrous silicate rocks as well as mixtures of the two.

Hematitic and limonitic cherts are variegated rocks, consisting of white, gray, or pink chert intermixed with more or less hematite or limonite. Commonly the chert and iron oxide occur interlaminated, forming a banded rock. Often, however, they are irregularly intermixed. Hematitic and limonitic cherts form the principal surface rocks of the iron-bearing formation. Ferruginous chert is a general term including both hematitic and limonitic cherts. Taconite is a granular ferruginous chert which occurs in the Mesabi district and is believed to be derived from the oxidation of greenalite rock.

Hematitic and limonitic slates are thinly laminated dark red to brown argillaceous rocks heavily impregnated with hematite or limonite. They show distinct banding and lamination and are of sedimentary origin. Ferruginous slate is a general term used to include both hematitic and limonitic slates. Paint rock is a term applied to soft altered phases of ferruginous slate. The term slate is perhaps a misnomer as applied to these rocks, since they only locally show slaty cleavage. They are rather indurated and metamorphosed shales for which the term argillite might be more properly used. The term slate, however, is in such general use for these rocks in the Lake Superior district that for the present it seems best to retain it.

Jaspilite, or banded jasper, is a hard, dense, recrystallized, ferruginous chert. Hematite and jasper generally occur interbanded, the former frequently being in the specular form.

Magnetitic slate, or, more properly, magnetitic argillite, is a dark, distinctly laminated rock containing amphibole, magnetite, quartz, and other constituents usually somewhat segregated in parallel bands. It is a metamorphosed phase of the original iron-bearing formation.

Amphibole-magnetite rock is similar to the magnetitic slate (or magnetitic argillite) but shows coarser banding and crystallization and usually contains more quartz.

Hematitic schist is a dark red, soft, homogeneous, schistose rock which is formed by alteration and impregnation with hematite from the green or gray chloritic schist which is commonly associated with the bands of iron-bearing formation. It is distinguished from ferruginous slate (or ferruginous argillite) in showing no distinct lamination and it is probably of igneous origin. The term paint rock is applied to hematitic schist as well as to ferruginous slate.

The term gneiss in this paper is applied to banded, metamorphosed, crystalline rocks which have approximately the composition of some deep-seated igneous rock. Usually they are siliceous in character. The distinct banding or lamination is a requisite.

Gneissoid granite is a granite which has suffered a certain amount of deformation or recrystallization so that the ferro-magnesian minerals have a somewhat parallel arrangement, giving the rock a foliated appearance. It does not show banding.

Greenstone is a general term applied to dark green, massive, igneous rocks which have suffered alteration so that the original character is not obvious in the hand specimen.

Green schist is a name given to dark green chloritic and amphibolitic rocks with schistose or slaty texture. Some are schistose greenstones, while others may be metamorphosed sediments. The more obviously laminated slaty green rocks of sedimentary origin are usually called green slates.

Phyllite is finely crystalline quartz-mica schist.

Slate is an indurated argillaceous rock showing slaty cleavage. It is usually very finely crystalline.

The term argillite is used in this paper to denote indurated argillaceous rocks which have no slaty cleavage, in contradistinction to the term slate. This usage, however, is not strictly adhered to because of the general use into which the term slate has come for all indurated, argillaceous rocks in the Lake Superior region.

GENERAL GEOLOGY OF MINNESOTA

The basal rocks of Minnesota consist of a complex of granite, gneiss, and greenstone of Archean age with some metamorphosed sediments. Lying on these and folded into them are Huronian quartzite, conglomerate, slate, schist, and iron-bearing formation, with locally crystalline limestone. These older rocks throughout much of the eastern part of the state are unconformably overlain by rocks of Keweenawan age, consisting in the north of flows and intrusive sheets of igneous rocks, both silicic and subsilicic, and in the south of red clastic sediments associated with detrital igneous rocks. The Keweenawan rocks also have suffered considerable deformation locally, but not to such a degree as the Huronian rocks. Keweenawan and Huronian silicic and subsilicic igneous rocks intrude older rocks as dikes, bosses, and sheets.

The pre-Cambrian rocks form the bed rock underneath the glacial drift throughout the northeastern part of the state and for a considerable distance west of the Mississippi River. In the southwestern part of the state also, several large patches of pre-Cambrian rocks are known to lie directly underneath the glacial drift. In the southeastern part of the state, however, the pre-Cambrian rocks are overlain by more or less flat-lying sediments of Paleozoic age, while throughout most of the western part of the state flat-lying, slightly consolidated, Cretaceous sediments occur overlying the pre-Cambrian rocks. The glacial drift forms a mantle covering the different bed rocks practically throughout the state.

The accompanying sections show the general relations between the rock strata in the southern and northeastern parts of the state.

General Section of Rocks in Southern Minnesota and Western Wisconsin[1]

		Approximate Maximum Thickness
Quaternary		
Recent	Alluvium	....
Pleistocene	Glacial till	575 feet
Cretaceous		
Benton shale	(soft blue shale and unconsolidated sandstone)	500 feet
Dakota sandstone	(white sandstone, shale, and red clay)	
Devonian	(limestone and sandstone)	100 feet
Ordovician		
Maquoketa shale	(shale, dolomite, and argillaceous sandstone)	100 feet
Galena limestone Decorah shale Platteville limestone	(limestone and shale)	350 feet
St. Peter sandstone	(white or yellow sandstone, with some shale)	200 feet

---

[1] Hall, C. W., Meinzer, O. E., and Fuller, M. L., Geology and underground waters of southern Minnesota: *U. S. Geol. Survey Water Supply Paper* 256, pp. 31-49. 1911.

Hall, C. W., The gneisses, gabbro-schists, and associated rocks of southwestern Minnesota: *U. S. Geol. Survey Bull.* 157. 1899.

Weidman, S., and Schultz, A. R., The underground and surface water supplies of Wisconsin: *Wis. Geol. and Nat. Hist. Survey Bull.* 35, pp. 25-43. 1915.

Winchell, N. H., Upham, W., and Harrington, M. W., (Geology of the southern counties of Minnesota), *Geol. and Nat. Hist. Survey of Minnesota, Geol. of Minnesota,* vols. I and II. 1884, 1888.

Prairie du Chien group ("Lower Magnesian")	
Shakopee dolomite (yellow, buff, pink, or red dolomite, with sandstone lenses)	75 feet
Oneota dolomite (buff to reddish dolomite)	200 feet
Cambrian	
Upper Cambrian	
Jordan sandstone (coarse-grained white sandstone)	50 feet
St. Lawrence formation (dolomite, shale, and sandstone)	60 feet
Franconia sandstone (fine-grained white or yellow sandstone, with fossils and some greensand)	160 feet
Dresbach sandstone (heavily bedded coarse sandstone)	100 feet
Eau Claire shale (interbedded shale and shaly sandstone)	250 feet
Mt. Simon sandstone (coarse sandstone)	250 feet
Algonkian (?)	
Keweenawan (?)	
Red clastic series (red sandstone and shale, with volcanic clastic rocks)	2,250 feet
Algonkian	
Huronian	
Sioux quartzite (red quartzite and pipestone)	Unknown
Crystalline schist (hornblende and biotite schists)	Unknown
Archean	
Granite, gneiss, and schist	Unknown

General Section of Rocks in Northeastern Minnesota and Adjacent Parts of Wisconsin[2]

	AVERAGE MAXIMUM THICKNESS
Quaternary	
Recent................Alluvium	....
Pleistocene............Glacial till	400 feet
Cretaceous	
Ferruginous conglomerate	Small
Algonkian	
Keweenawan	
Upper Keweenawan	
Bayfield group (In older reports mistaken for Cambrian, Lake Superior sandstone)	
Chequamegon sandstone (red and white quartz sandstone)	1,000 feet
Devils Island sandstone (pink and white sandstone)	300 feet
Orienta sandstone (red and white sandstone)	3,000 feet

---

[2] Van Hise, C. R., and Leith, C. K., Geology of the Lake Superior region: *U. S. Geol. Survey Mon.* 52, pp. 118-224, 370-380. 1911.

Thwaites, F. T., Sandstones of the Wisconsin coast of Lake Superior: *Wis. Geol. and Nat. Hist. Survey, Bull.* 25. 1912.

Winchell, N. H., Upham, W., Todd, J. E., and Grant, U. S. (Geology of the central and northern counties of Minnesota), *Geol. and Nat. Hist. Survey of Minn., Geol. of Minn.*, 2 and 4. 1888 and 1899.

Oronto group			
Amnicon formation (red and green shale and arkose)	5,000 feet		
Eileen sandstone (red and white feldspathic sandstone)	2,000 feet		
Freda sandstone (red arkose sandstone)	12,000 feet		
Nonesuch shale (black shale)	300 feet		
"Outer" conglomerate	1,200 feet		
Middle Keweenawan			
Diabase sills and laccoliths	Varying		
Diabase amygdaloid, melaphyr, quartz porphyrite, and felsite extrusives, with interlayered conglomerate in upper part	4,000–20,000 feet		
Red rock, intrusive into Duluth gabbro and older rocks	....		
Duluth gabbro, laccolith at base of middle Keweenawan	9,500–25,000 feet+		
Lower Keweenawan			
Puckwunge conglomerate	100–400 feet		
Huronian			
Upper Huronian (Animikie group)			
Virginia ("St. Louis") and Rove slates (argillaceous, siliceous, and carbonaceous slate, with lenses of quartzite, grit, graywacke, limestone, and iron-bearing formation)	Unknown		
Biwabik and Gunflint formations (iron bearing)	620 feet		
Pokegama quartzite	200 feet		
Lower-middle Huronian			
Giants Range and other granites	....		
Knife Lake slate	Unknown	Slate and graywacke of Mesabi Range	3,000–5,000 feet
Agawa formation (iron bearing)	0–50 feet		
Ogishke conglomerate	0-2000 feet		
Archean			
Laurentian			
Granite and gneiss			
Keewatin			
Soudan formation (iron bearing)		Greenstone, green schist, slate, and graywacke of Lake of the Woods region	
Ely greenstone			

As shown by these sections, the rocks of Minnesota consist of a great series of pre-Cambrian plutonic, volcanic, metamorphic, and sedimentary rocks overlain in places by a comparatively thin veneer of Paleozoic and Mesozoic rocks and more generally by a thin but wide-spread blanket of glacial deposits.

The complex of pre-Cambrian metamorphic rocks and associated intrusives is comparatively near the surface in the southwestern, central, and northeastern parts of the state, and surface outcrops are abundant in many places. In the northwestern part also these rocks are at no great depth, although outcrops are less common. In the southeastern part, however, a marked depression in their surface occurs in the form of a northeast-southwest basin, the bottom of which is several thousand feet below the general elevation of the pre-Cambrian rock surface in other parts of the state.[3] It is in this basin that the Keweenawan red clastic rocks occur, as well as the overlying Paleozoic sediments.

A basin probably existed over part of this area before the Paleozoic sediments were deposited, but some sinking has taken place since that time. The original depression is believed to have been caused by deformational forces resulting in a tilting to the southeast. The relief of the pre-Cambrian surface before deposition of the Paleozoic sediments was very marked and the present approximately level pre-Cambrian rock surface in the northern and western parts of the state is due to subsequent peneplanation.[4] Only locally in the southwestern part and beneath the sedimentary rocks in the southeastern part is the old uneven bed rock surface preserved.

In southern Minnesota the principal pre-Cambrian rocks are granite, gneiss, Sioux quartzite, crystalline schists, and probably the red clastic series. Granite and gneiss are abundantly exposed along Minnesota River and at several localities in the region to the south. Elsewhere they are generally overlain by a thin layer of Cretaceous sediments. Hall[5] states that wherever the crystalline rocks have been encountered underneath the Cretaceous strata in drilling they have been found to be profoundly decomposed. Directly underneath the Cretaceous strata there is usually a layer of white clay varying in thickness up to 50 feet, which grades downward into decomposed granite or gneiss of yellow, red, or gray color. The Cretaceous itself consists principally of blue and red shale with some fine white quartz sandstone, products of decomposition of the underlying crystalline rocks. This decomposition indicates a long period of erosion previous to the deposition of the Cretaceous beds which probably extended through the Paleozoic and most of the Mesozoic era. That the residual material accumulated to such depths would indicate that the land surface during at least the latter part of the erosion period was low and comparatively level, though at the beginning of the Paleozoic there was probably considerable relief, as has already been stated.

The Sioux quartzite is exposed at a number of places in southwestern Minnesota and probably forms the bed rock in most of the southwestern corner of the state. It consists largely of red quartzite, but locally thin layers of red slate (pipestone) occur in it. While the quartzite is hard and indurated and has suffered some folding, ripple marks and cross-bedding are still visible in it.[6] Its relation to the granite, gneiss, and crystalline schists on the one hand and to the red clastic series on the other hand is not known. The Sioux quartzite may lie unconformably above the crystalline rocks, or the crystalline rocks may be in part intrusive into it. Its relation to the red clastic series also is not determined. Although apparently much more indurated and of somewhat different composition, it is not impossible that it may be of the same age as the red clastic rocks. Winchell and Upham[7] believed that the Sioux quartzite, the red clastic series, and the supposed upper Keweenawan sediments south of Lake Superior (the latter formerly believed to be the same as the upper Cambrian Lake Superior sandstone of Michigan), are all of lower Cambrian age. Hall[8] on the other hand states that the red clastic rocks are the southward continuation of the Keweenawan of the Lake Superior region but that the Sioux quartzite is not related to them. In general it has been held by geologists that the Sioux quartzite is probably of Huronian age.

---

[3] Hall, C. W., Meinzer, O. E., and Fuller, M. L., *op. cit.* pp. 32-33.

[4] *Ibid.*, p. 33.

[5] *Ibid.*, p. 49.

[6] *Ibid.*, p. 32.

Hornblende and biotite schist which are believed to be the southwestward continuation of the Huronian schist and slate which occur in east central Minnesota, have been encountered in well-drilling in the western part of the state north of Minnesota River.

The red clastic series of southern Minnesota is only known from deep drilling. Outcrops of it are wanting, the beds being everywhere covered either by drift or by a considerable thickness of Paleozoic sediments ranging in age from Upper Cambrian to Devonian. The red clastic beds consist principally of red sandstone and shale, but conglomerate beds also occur in it and volcanic clastic material is found locally. The finer sediments are found mainly in the upper part. The series apparently lies conformably beneath the known Upper Cambrian and unconformably above the pre-Cambrian crystalline rocks. Their age has not been determined, but because of their lithological similarity to the sandstone occurring on the south shore of Lake Superior in Wisconsin, which has recently been referred to the upper Keweenawan,[9] it is supposed that they are equivalent. The continuation of one into the other, however, has not been proven because of the scarcity of exposures in east central Minnesota and because of the general similarity between the red clastic rocks and the rocks forming the lower portion of the Upper Cambrian.

In northern Minnesota outcrops of pre-Cambrian rocks are abundant in many places, and a much more complex series of them has been found to exist than occurs in the southern part of the state. There are Archean metamorphic and igneous rocks, Huronian intrusive rocks, and metamorphosed sediments, and Keweenawan intrusive and extrusive rocks and sediments. These rocks have been studied in considerable detail in several districts, particularly in the Mesabi and Vermilion iron-ore districts and along the north shore of Lake Superior.[10] They have been shown to be of great complexity both in structure and distribution. The Archean rocks are most abundant along the northern boundary of the state and to the southward Huronian and Keweenawan rocks appear with increasing prominence.

---

[7] Winchell, N. H., and Upham, W., *Geol. and Nat. Hist. Survey of Minn., Geol. of Minn.* vol. 1, pp. 422, 424, and 537. 1882.

[8] Hall, C. W., Meinzer, O. E., and Fuller, M. L., *op. cit.*, p. 48.

[9] Thwaites, F. T., *op. cit.*

The Archean rocks are principally Laurentian granite and gneiss and Keewatin greenstone. The greenstone is either massive or schistose and locally contains metamorphosed sediments, such as iron-bearing formation in the Vermilion district and slate and graywacke in the Lake of the Woods region. In some localities the greenstone has suffered so little deformation that original structures are still clearly visible, while elsewhere it has been metamorphosed to such an extent as to be transformed into green chloritic schist. Large and small masses of Laurentian granite and gneiss occur intruded into the greenstone in the form of batholiths, bosses, and dikes. Much of the granite has been rendered gneissoid by later deformation and recrystallization so that now great areas in northern Minnesota are underlain by coarse gneiss and all gradations from granite to gneiss occur. In composition the Laurentian intrusives vary from granite to syenite and texturally both granitic and porphyritic types occur. Special phases of the intrusives are felsitic rocks, such as rhyolitic and trachytic porphyries.

Metamorphosed sedimentary rocks of lower-middle Huronian age are not very extensively distributed in northern Minnesota. In the Vermilion district this series is represented by the Ogishke conglomerate, iron-bearing Agawa formation, and Knife Lake slate. The conglomerate occurs at the base, and is overlain locally by Agawa iron-bearing formation, and above this is the Knife Lake slate.

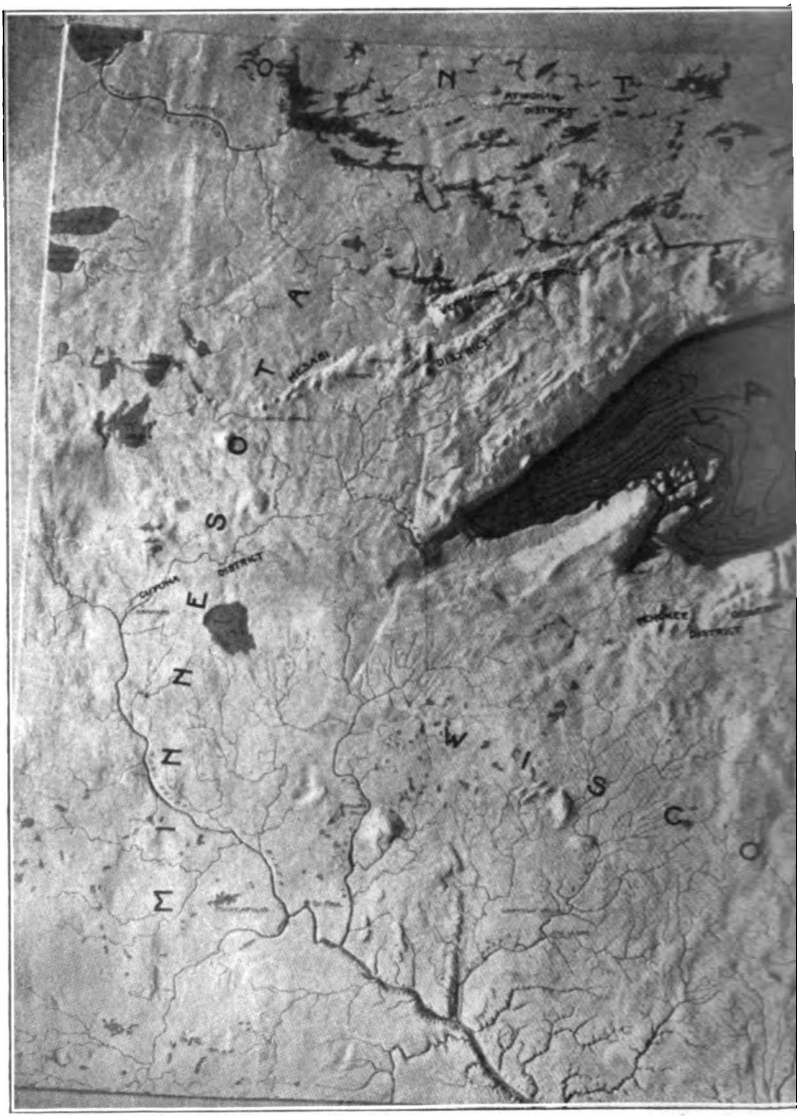
The Ogishke conglomerate varies extremely in thickness in different parts of the district. It has been thoroughly indurated and locally pronounced metamorphism has resulted in the development of schistose phases while intense folding has brought about complex relations between it and the underlying Archean. The materials composing the conglom-

---

[10] Van Hise, C. R., and Leith, C. K., *op. cit.*, pp. 118-210.

Leith, C. K., The Mesabi iron-bearing district of Minnesota. *U. S. Geol. Survey, Mon.* 43. 1903.

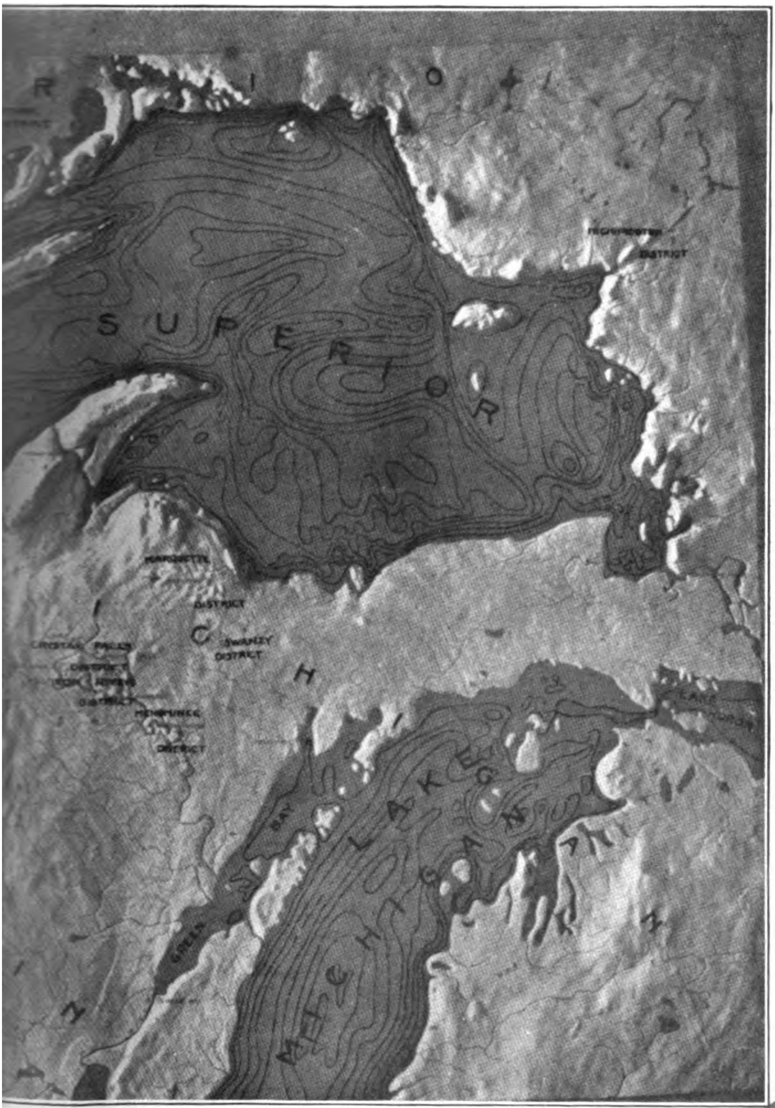
Clements, J. M., The Vermilion iron-bearing district of Minnesota. *U. S. Geol. Survey, Mon.* 45. 1903.



RELIEF MAP OF THE LAKE SUPERIOR DISTRICT SHOWING T

SCALE, I IN

PLATE I



OF THE IRON-ORE DISTRICTS, AFTER VAN HISE AND LEITH
60 MILES

UNIV. OF MICH.

erate have been derived from the underlying Keewatin and Laurentian rocks, pebbles of greenstone, granite, porphyry and jasper being found in it.

The Knife Lake slate covers considerable areas and is of great thickness. It includes many different phases such as argillaceous slate, biotitic, amphibolitic, quartzitic, and sericitic schists, graywacke, and conglomerate. Its metamorphism has been intense, and complex folding has resulted in the development of secondary structures, such as cleavage and schistosity, throughout the formation.

The iron-bearing Agawa formation occurs as thin lenses or layers below the Knife Lake slate and above the Ogishke conglomerate. It consists of ferruginous chert, jasper, and other iron-bearing rocks interbedded with layers of slate.

In the Mesabi district the lower-middle Huronian is represented by a thick series of slate, graywacke, and conglomerate. These rocks occur in local areas, being complexly infolded into the underlying Keewatin greenstone. Metamorphism has resulted in the development of cleavage and fissility, and in the formation of secondary minerals, such as sericite, biotite, and chlorite. The conglomeratic phases particularly show the effects of metamorphism in the elongation of pebbles and the recrystallization and alteration of minerals.

In general the lower-middle Huronian metamorphosed sediments have a complex distribution, occurring in local irregular areas with intricate structural relation with the underlying Archean. In some localities they appear to have suffered practically as much metamorphism as the Keewatin greenstone itself.

The lower-middle Huronian sediments are intruded by the Giants Range granite, principally a pink to gray hornblende granite, low in quartz, which occupies a large area north of the Mesabi district. Silicic intrusives of lower-middle Huronian age are abundant in many parts of the Lake Superior region. They are difficult to distinguish from the Laurentian intrusives, however, and it is only in the more recent detailed geologic work in which the relations between the intrusives and the associated metamorphosed sediments have been carefully studied that the separation has been possible.

On the eroded surface of the Archean and lower-middle Huronian rocks lie the much less deformed upper Huronian or Animikie beds. The Animikie group in northern and central Minnesota consists in general of a thick slate formation at the base of which are comparatively thin layers of iron-bearing formation and quartzite. The principal area of Animikie rocks in Minnesota begins at the international boundary near Gunflint Lake and runs southwestward as a narrow, discontinuous strip to the

Mesabi district where it widens and spreads out over most of east central Minnesota as far southward as Mille Lacs Lake. In the Mesabi district the Animikie rocks lie on the south slope of the Giants Range and have a gentle dip to the southeast. The Pokegama quartzite occurs at the base of the group. It is a thin but fairly continuous bed consisting of vitreous quartzite, which locally gives place to micaceous quartzitic argillite and elsewhere is conglomeratic.

The iron-bearing Biwabik formation which lies above the quartzite is somewhat thicker than the latter and is continuous throughout the length of the Mesabi district. It contains various common phases of the iron-bearing formation such as ferruginous chert of the form known as taconite, ferruginous slate, iron ore, greenalite rock, and quartz-amphibole-magnetite rock. The principal part of the iron-bearing formation consists of taconite. The ferruginous slate occurs in this as layers and lenses some of which are quite continuous and may be traced from mine to mine.[11] Quartz-amphibole-magnetite rock is found at the eastern end of the Mesabi district and has resulted from the metamorphism of the original iron-bearing formation by the Keweenawan gabbro intrusion. Iron ore occurs as local concentrations in the taconite, while remnants of greenalite rock are found in places where the iron-bearing formation has been protected from oxidation.

The Virginia slate, which overlies the Biwabik formation, consists of argillaceous and carbonaceous slate with local layers of siliceous slate and graywacke. It forms the main upper portion of the Animikie group throughout east central Minnesota, having a great but unknown thickness. In the Mesabi district this rock is usually soft and but slightly metamorphosed, although mica occurs in it locally. It shows no secondary cleavage, being really an argillite or indurated shale. South of the Mesabi district, however, along St. Louis River near Cloquet and Carlton, the slate, which in the past has been called "St. Louis slate," but which Van Hise and Leith referred to as the Virginia slate, has suffered metamorphism and deformation to a marked degree, as have also the slate and garnetiferous and staurolitic schist exposed along Mississippi River near Little Falls.

The schists, slates, and related rocks of the Cuyuna district and the adjacent region are also correlated with the Virginia slate by Van Hise and Leith and are believed to be of upper Huronian or Animikie age. They are principally sericitic, biotitic, and chloritic schist, slate, and phyllite with locally lenses of black, carbonaceous slate and some quartzite and quartzitic schist. A prominent member of the series is the Deerwood iron-bearing member, which occurs as layers and lenses interbedded with the schist. The rocks of the Cuyuna district have been complexly folded into a series of close anticlines and synclines striking northeast-southwest. The beds usually have very steep dips either to the southeast or northwest, while the pitch of the folds is usually very low so that frequently the crests of the anticlines are horizontal for long distances. The rocks of the Cuyuna district will be described in more detail later.

---

[11] Wolff, J. F., Recent geologic developments on the Mesabi iron range, Minnesota. *Bull. Amer. Inst. Min. Engrs.*, Oct., 1916, pp. 1763-1787.

Overlying the older rocks in northeastern and eastern Minnesota, and intruded into them, are rocks of Keweenawan age. The oldest of these are sedimentary beds supposed to be of lower Keweenawan age, which occur unconformably overlying the Animikie rocks at several places in northeastern Minnesota. Among them is the Puckwunge conglomerate found along St. Louis River west of Duluth.

The principal Keweenawan rocks of northern and eastern Minnesota are intrusive and extrusive igneous rocks of middle Keweenawan age. They form a large area extending along the north shore of Lake Superior from Duluth northeasterly into Canada, and a smaller area along the upper St. Croix River south of Lake Superior. The extrusive rocks occurring along the north shore of Lake Superior are mainly diabase amygdaloids, but important layers of felsite and quartz porphyrite occur locally. The principal intrusive rock is the Duluth gabbro which forms an extensive laccolith at or near the base of the lavas. Smaller sills and sheets of diabase, such as the Beaver Bay laccolith, are found intrusive in the volcanic rocks at several horizons. The rocks in the area along St. Croix River are mainly extrusive rocks of amygdaloid type, associated with crystalline phases, such as diabase, and with beds of tuff and volcanic breccia.[12] Thin layers of conglomerate occur locally.

Sediments of upper Keweenawan age are abundant along the south shore of Lake Superior extending from Superior eastward into northern Michigan. They consist mainly of red and white sandstone and arkose with increasing shale in the lower part and a thick conglomerate at the base. The upper portion of the series, recently classed as the Bayfield group of the upper Keweenawan,[13] has generally been called Lake Superior sandstone and included in the Cambrian,[14] while the lower portion, known as the Oronto group, has always been classed as upper Keweenawan. Certain of the formations in the Bayfield group, extend southwestward into Minnesota, but their extent and distribution are not known, due to lack of exposures. At some point east or southeast of Mille Lacs Lake they give place to the lower members of the fossiliferous Upper Cambrian series extending northward from southeastern Minnesota and western Wisconsin. This boundary has not yet been located. It seems probable that the red clastic series, which underlies the Upper Cambrian rocks in southeastern Minnesota, emerges from beneath the latter on going northward and comes to the bed rock surface in east central Minnesota. In this case it might be directly continuous with the Bayfield group extending southwestward from Lake Superior.

---

[12] Grout, F. F., Contribution to the petrography of the Keweenawan: *Jour. Geology*, vol. 18, pp. 633-657. 1910.

[13] Thwaites, F. T., *op. cit.*

[14] Van Hise, C. R., and Leith, C. K., *op. cit.*, pp. 378-379, 415, 616.

The Paleozoic rocks of southeastern Minnesota range from Upper Cambrian to Devonian in age.[15] They consist in general of interlayered, comparatively thin beds of sandstone, limestone, and shale. The upper beds, such as the Devonian, are found only in the southeastern part of the state while successively older formations come to the bed-rock surface on going northward. Thus the Platteville limestone and St. Peter sandstone constitute the principal surface rocks in the region adjacent to St. Paul and Minneapolis, while the Oneota and Shakopee dolomites and the upper members of the Upper Cambrian form outcrops along St. Croix River below Taylor's Falls. Above Taylor's Falls various Upper Cambrian strata occur along St. Croix River continuing northward until they give place to Keweenawan trap rock.

The Paleozoic beds are very uniform in character. For this reason and because of the abundance of fossils in them, even thin beds can be recognized over great areas. The lower portion of the Paleozoic section represents a fairly continuous period of deposition, although minor unconformities may occur.[16] A marked break, however, is found in the upper part, for the Devonian strata rest unconformably on the eroded surface of the Ordovician, indicating an erosion period covering the Silurian and part of the Devonian. The uniformity in the lithology and general character of the Paleozoic beds over large areas presents a strong contrast to the pre-Cambrian rocks of the State, which as a rule are most irregular in their lithology and stratigraphy.

The mantle of Cretaceous rocks, although thin, is fairly continuous throughout the western part of Minnesota, while isolated areas of various sizes occur also in the eastern part. In the southern and western parts of the State these rocks consist typically of thick beds of plastic gray-blue shale associated with thin beds of white sandstone.[17] The latter occur mainly in the upper and lower parts of the series. Locally beds of red clay are found.

---

[15] Hall, C. W., Meinzer, O. E., and Fuller, M. L., *op. cit.*, pp. 31-48.
[16] *Ibid.*, p. 33.
[17] *Ibid.*, p. 42.

In the east central and northern parts of the State isolated patches of Cretaceous sediments are found in many places. In the Mesabi and Cuyuna districts they consist mainly of ferruginous conglomerate associated with argillaceous material. Elsewhere, however, as along Mississippi and Sauk rivers in the central part, beds of slightly consolidated calcareous clay and sand are found.

ROCKS OF EAST CENTRAL MINNESOTA

PREVIOUS GEOLOGIC WORK

The first geological investigations of any considerable importance made in east central Minnesota were those of R. D. Irving and E. T. Sweet in connection with similar work in northern Wisconsin.[18] The work was done between 1873 and 1879 and consisted in an examination of Keweenawan and Huronian rocks adjacent to the Wisconsin boundary. In a report[19] published in 1880, Irving stated his belief that the slates occurring along St. Louis River were to be correlated with the iron-bearing rocks of the Penokee region, and that they probably occupied the northern limb of a syncline of which the rocks of the Penokee district formed the southern limb. At this time no subdivision had as yet been made of the Huronian rocks and the schists, slates, and other metamorphosed sediments of northern and central Minnesota and neighboring regions were all grouped together as Huronian to distinguish them from the overlying Keweenawan and from the granite and gneiss, these three being the only subdivisions of the pre-Cambrian recognized at that time.

The investigations of the United States Geological Survey began in this region about 1880 under the direction of R. D. Irving assisted by C. R. Van Hise and W. N. Merriam. Brief reconnaissance surveys were made in the early 80's in central and northern Minnesota and the first general geologic map of the Lake Superior region to be published by the United States Geological Survey appeared in 1883.[20] On this map the Huronian metamorphosed sedimentary rocks of northern and eastern Minnesota, including those of the Vermilion district as well as those occurring along the Giants Range or Mesabi Range, are all grouped with the Animikie rocks of the north shore of Lake Superior, and the slates and schists occurring along St. Louis and Kettle rivers are connected directly with the Animikie rocks on the north shore. The Animikie rocks at this time apparently were regarded as a somewhat less metamorphosed phase of the other Huronian rocks without recognition of difference in age. Apparently it was not then recognized that the less metamorphosed rocks of the Mesabi district are younger than the highly metamorphosed slates and associated rocks of the Vermilion district.

---

[18] Irving, R. D., The geological structure of northern Wisconsin: *Geol. of Wis.*, vol. III, Survey of 1873-79, p. 18. 1880.

Sweet, E. T., Geology of the western Lake Superior district: *Geol. of Wis.*, vol. III, Survey of 1873-79, p. 334 et seq., 1880.

[19] Irving, R. D., *op. cit.*

[20] Irving, R. D., The copper-bearing rocks of Lake Superior: *U. S. Geol. Survey Third Ann. Rept.*, 1881-1882, p. 162 and Pl. III. 1883.

Irving, R. D., The copper-bearing rocks of Lake Superior: *U. S. Geol. Survey Mon.* 5, p. 384 and Pl. I. 1883.

In a later report accompanied by a general map,[21] Irving correlates the "St. Louis" slate with the slates and schists occurring along Mississippi River in the vicinity of Little Falls, and on the basis of this correlation an area of Huronian metamorphosed rocks is shown in east central Minnesota extending from Duluth southwestward to Mississippi River, including the present Cuyuna district and the northern part of Mille Lacs Lake. It is shown as being bounded on the south and west by areas of granite the age of which is not given, and on the north by a drift-covered area in which the bed rock is unknown. The area of Huronian rocks of east central Minnesota is not directly connected with the Animikie area extending from the Giants Range northeastward along the north shore of Lake Superior as was done in the previous report, but the statement is made that they are probably equivalent to them.

In 1888 Irving published a map of northeastern Minnesota[22] in which the Animikie rocks occurring along the Giants Range are mapped as extending southward into east central Minnesota without a break. On this map the metamorphosed sediments of the Vermilion district and of the international boundary are separated from the Animikie rocks of the north shore of Lake Superior and of the Giants Range because of their greater metamorphism, but it is believed nevertheless that they are equivalent in age, the difference in lithology being due to difference in the intensity of metamorphism. The granite and gneiss of northern and central Minnesota, which had hitherto been left unclassified, are placed in the Laurentian, and with them are grouped certain green schists and mica schists which were believed to be older than Huronian. The following classification of the pre-Cambrian rocks is used. It is of interest because it is the forerunner of the classification used at present by the United States Geological Survey for Lake Superior rocks.

---

[21] Irving, R. D., Preliminary paper on an investigation of the Archean formations of the northwestern states: *U. S. Geol. Survey Fifth Ann. Rept.*, 1883-1884, pp. 196-197. 1885.

[22] Irving, R. D., Classification of early Cambrian and pre-Cambrian formations: *U. S. Geol. Survey Seventh Ann. Rept.*, 1885-1886, pp. 417-423. 1888.

- Cambrian
  - Potsdam sandstone
- Keweenawan
  - Volcanic flows and sediments
  - Basal intrusive gabbro
- Huronian
  - Animikie series
  - Vermilion Lake iron-bearing series
- Laurentian
  - Green schists
  - Mica schists
  - Granite

In 1892, C. R. Van Hise published a report on the pre-Cambrian rocks of North America, which contains a section on the geology of the Lake Superior region.[28] A general table shows the correlation of rocks in different parts of the region, the following subdivisions being used:

- Algonkian
  - Keweenawan
  - Upper Huronian
  - Lower Huronian
- Archean
  - Mareniscan
  - Laurentian

This is a further stage in the development of the classification of Lake Superior pre-Cambrian rocks. As regards the application to the rocks of northern and central Minnesota, it is similar to those previously used except that the term Archean is substituted for Laurentian, the latter term being restricted to intrusive granite and gneiss, while a new term, Mareniscan, is used to cover the older metamorphic rocks, such as green schists and mica schists. The younger metamorphosed sediments (Huronian) which are grouped together with the Keweenawan under the general subdivision Algonkian, are definitely separated into two series, the earlier (lower Huronian) including the metamorphosed sediments of the Vermilion region, which had formerly been but indefinitely separated from the Animikie, and the later (upper Huronian) including the Animikie rocks and "St. Louis" slate. A map accompanying this discussion shows the general geology of the Lake Superior region and is very similar to the maps previously published. On it the "St. Louis" slate is shown as extending across east central Minnesota, including the present

---

[28] Van Hise, C. R., Correlation papers: Archean and Algonkian: *U. S. Geol. Survey Bull.* 86, pp. 51-208. 1892.

Cuyuna district and Little Falls region, being bounded on the west and south by granite classified as Archean.

While this work was being done by the United States Geological Survey, N. H. Winchell, Warren Upham, and others of the Geological and Natural History Survey of Minnesota, were also engaged in extensive geological investigations in central and northern Minnesota. The work of the Minnesota survey began in 1872, but during the early years it was confined largely to the southern part of the state. Later, however, extensive investigations were made on the crystalline and metamorphic rocks of central and northern Minnesota. The work consisted chiefly in the mapping of rock outcrops[24] in this region, but attempts were also made by Winchell to correlate the various rock formations with similar rocks in the neighboring states, in Canada, and in New England.[25]

This resulted in the adoption of a somewhat different nomenclature from that used by geologists of the United States Geological Survey. The table on the following page shows the classification of Lake Superior rocks used by the Geological and Natural History Survey of Minnesota, as compared with that used later in reports of the United States Geological Survey.[26]

This classification was partly the outcome of work by Winchell in northern and eastern Minnesota, and partly of work by A. C. Lawson in the Lake of the Woods and Rainy Lake regions for the Geological and Natural History Survey of Canada.[27] Not only does the nomenclature itself differ from that used by the United States Geological Survey, but the position assigned to many of the rock formations in the stratigraphic series is radically different. Perhaps the most fundamental difference in the two classifications is that the entire "Taconic series" is classed as Paleozoic by Winchell, being regarded as analogous to the so-called Taconic rocks of New England. The rest of the crystalline and metamorphic rocks are classed as Archean, no Algonkian being recognized. There is no distinction made by Winchell and Lawson between the rocks of the lower Huronian and those of the Keewatin, all being grouped together under the term Keewatin, while the Vermilion series included the Coutchiching rocks of Lawson, as well as various other crystalline schists of northern and central Minnesota. In this group, which Winchell at first designated as Montalban, were placed the garnetiferous and staurolitic schist found along Mississippi River near Little Falls, as well as certain gneisses occurring in Morrison County east of Little Falls. The Animikie of Winchell included the original Animikie rocks on the north shore of Lake Superior, the iron-bearing series of the Mesabi district, and the slates occurring along St. Louis River, but did not include the slates and schists of the Kettle River region, these being classed by Winchell as Keewatin on account of their greater metamorphism.

---

[24] Winchell, N. H., Upham, Warren, and others, *Geol. and Nat. Hist. Survey of Minn.*, *Geol. of Minn.*, vols. 2, 4, and 6. 1882-1901.

Upham, Warren, Notes of rock outcrops in central Minnesota: *Geol. and Nat. Hist. Survey of Minn. Eleventh Ann. Rept.*, pp. 86-136 and Pl. I. 1882.

[25] Winchell, N. H., The crystalline rocks of the northwest: *Geol. and Nat. Hist. Survey of Minn. Thirteenth Ann. Rept.*, pp. 124-140. 1884.

............, The crystalline rocks of Minnesota: *Geol. and Nat. Hist. Survey of Minn. Seventeenth Ann. Rept.*, pp. 5-74. 1888.

............, The crystalline rocks: *Geol. and Nat. Hist. Survey of Minn. Twentieth Ann. Rept.*, pp. 1-28. 1891.

[26] Winchell, N. H., Note on the age of the rocks of the Mesabi and Vermilion iron districts: *Geol. and Nat. Hist. Survey of Minn.*, *Eleventh Ann. Rept.*, pp. 168-170. 1882.

............, Pre-Silurian rocks of Minnesota: *Geol. and Nat. Hist. Survey of Minn.*, *Twenty-first Ann. Rept.*, Table opp. p. 4. 1892.

Winchell, N. H., Upham, Warren, and others, *Geol. and Nat. Hist. Survey of Minn.*, *Geol. of Minn.*, vol. 6, Geological map—frontispiece. 1900-1901.

[27] Lawson, A. C., Report on the geology of the Lake of the Woods region, with special reference to the Keewatin (Huronian?) belt of Archean rocks: *Geol. and Nat. Hist. Survey of Canada, Ann. Rept. for 1885*, vol. 1 (new series) pp. 5-151. CC.

............, Report on the geology of the Rainy Lake region: *Geol. and Nat. Hist. Survey of Canada, Ann. Rept. for 1887-1888*, vol. 3 (new series) pp. 1-196 F.

............, Lake Superior stratigraphy: *Am. Geol.*, vol. 7, pp. 320-327. 1891.

Minnesota Geological and Natural History Survey	*United States Geological Survey*
Paleozoic	*Paleozoic*
Upper Cambrian	Upper Cambrian
Taconic	*Algonkian*
Keweenawan (Nipigon)	Keweenawan
Upper	Upper
Brown sandstone	
Lower	Middle
Traps and amygdaloidal rocks	
Gabbro and anorthosite	Lower
Animikie	Huronian
Metamorphosed sediments,	
including Mesabi series,	Upper
Sioux quartzite, and	
others	Middle
Archean	Lower
Ontarian	
Keewatin	*Archean*
Sericitic and green schists, slate,	Laurentian
graywacke, and other meta-	
morphosed rocks of Vermilion district	Kewatin
Vermilion (Montalban, Coutchiching)	
Holocrystalline hornblende and mica schists	
Laurentian	
Gneiss	

The slate, graywacke, and schist of St. Louis and Kettle rivers, and of the Little Falls region, which were all believed by geologists of the United States Geological Survey to be of approximately the same age, were not so regarded by Winchell, who grouped them under three different subdivisions, the more highly metamorphosed rocks being placed in the Archean and the less highly metamorphosed ones in the Taconic.

In 1894, J. E. Spurr published an article on the so-called "Thomson" or "St. Louis" slate[28] in which he brings forth various arguments why these slates should be classed as "Keewatin (lower Huronian)" rather than as Animikie (upper Huronian) as had been done hitherto. He bases his arguments chiefly on the lithological similarity of the "St. Louis" slate with what he calls "Keewatin (lower Huronian)" rocks of the Mesabi district, and on the fact that secondary structures, such as cleavage, seem to indicate that they suffered deformation by the same dynamic forces. In his paper the slates and schists of the Kettle River region and of the Little Falls region are also classed as "Keewatin (lower Huronian)" and are believed to be directly continuous with the "St. Louis" slate.

The first general report of the United States Geological Survey on the iron ores of the Lake Superior region was published in 1901.[29] It contains a short discussion of the general stratigraphy of the Lake Superior region, and more detailed descriptions of the geology of the Vermilion and Mesabi districts. The classification of the rocks is similar to that in present use, with the exception that the middle Huronian had not yet been recognized. The general terms Archean and Algonkian are used. The Archean includes the greenstones, various schists, and associated iron-bearing formation as well as the older granites and gneisses. The Algonkian is divided into (1) lower Huronian, which includes various highly metamorphosed sediments of the Vermilion and Mesabi districts, (2) upper Huronian, which includes the iron-bearing rocks of the Mesabi district and of the Gunflint area, and (3) Keweenawan, under which are grouped various later igneous and sedimentary rocks. It is recognized that not all the silicic igneous rocks of the region are Archean in age, but that later intrusive rocks occur such as the lower Huronian granite of the Giants Range. No special reference is made to the slates and schists of eastern and central Minnesota.

Various monographs of the United States Geological Survey describing the iron ores of the Lake Superior region, which were published between 1892 and 1900, contain discussions of the general geology of the region, but the first ones which dealt directly with the geology of Minnesota were the monographs on the Vermilion and Mesabi iron-ore districts[30] which appeared in 1903.

---

[28] Spurr, J. E., The stratigraphic position of the Thomson slates: *Amer. Jour. Sci.*, 3d ser., vol. 148, pp. 159-166. 1894.

[29] Van Hise, C. R., The iron-ore deposits of the Lake Superior region: *U. S. Geol. Survey, Twenty-first Ann. Rept.*, pt. 3, pp. 307-434. 1901.

In the monograph on the Vermilion district, the various intensely metamorphosed Huronian rocks of northern Minnesota are classified under subdivisions of the lower Huronian, while the greenstone, green schist, and associated iron-bearing formation are placed in the Keewatin series of the Archean. Silicic intrusives of two ages are recognized, those north of the Vermilion district being mapped as Laurentian, while those south of the district are mapped as lower Huronian.[31] The crystalline and metamorphic rocks of northern Minnesota were thus definitely correlated with similar rocks in northern Wisconsin and Michigan described in the earlier monographs.

In the monograph on the Mesabi district, the iron-bearing rocks are classed as upper Huronian while certain metamorphosed slates and graywackes included in the Archean by Winchell, Grant, and Spurr[32] of the Minnesota survey, are included in the lower Huronian. The Giants Range granite is classified as lower Huronian, while a supposedly later granite, the Embarrass granite, believed to be intrusive into the upper Huronian, is included in the Keweenawan.

An interesting discussion in the report deals with a possible connection between the upper Huronian rocks of the Mesabi district of Minnesota and those of the Penokee-Gogebic district of Michigan and Wisconsin.[33] It is accompanied by a map showing the hypothetical course of a possible iron-bearing belt extending southwestward from the western end of the Mesabi district for some distance and then turning and running eastward through the present Cuyuna district almost to Duluth, at which point it again turns, and after running southwestward for a considerable distance, makes several more turns and then connects with the western end of the Penokee-Gogebic iron-bearing belt. The existence of such a connecting belt was based on the similarity in lithology and succession of the rocks of the Mesabi district with those of the Penokee-Gogebic district, while its general trend was suggested by the structure of the Lake Superior syclinorium and by a number of scattered rock outcrops. Its course through the Cuyuna district was determined by certain quartzite exposures near Dam Lake three miles south of the town of Kimberly, which are identical in lithology with the Pokegama quartzite of the Mesabi district. On the shore of Long Lake, southwest of Dam Lake, are outcrops of subsilicic igneous rocks which were presumed to be equivalent to the Archean greenstone of the Mesabi district and to underlie this quartzite. Variations in magnetic attraction had been reported at various times from localities in Crow Wing and Aitkin counties, and these were considered as additional evidence for drawing the supposed iron-bearing belt through the Cuyuna district. Leith at this time, following Spurr,[34] supposed that the slate outcrops at Carlton and Cloquet and at Little Falls were of lower Huronian age, and believed that they were southwest of the iron-bearing belt and within the area of the underlying lower Huronian and Archean. In the latter were included also the granite outcrops occurring at Staples, St. Cloud, and at various places west, south, and southeast of Mille Lacs Lake.

---

[30] Clements, J. M., The Vermilion iron-bearing district of Minnesota: *U. S. Geol. Survey, Mon.* 45. 1903.

Leith, C. K., The Mesabi iron-bearing district of Minnesota: *U. S. Geol. Survey, Mon.* 43. 1903.

[31] Clements, J. M., *op. cit.*, pp. 33 and 275-395.

[32] Grant, U. S., and Winchell, N. H., (Detailed geology of areas in northeastern Minnesota), *Geol. and Nat. Hist. Survey of Minn., Geol. of Minn.*, vol. 4, 1896-1898, pp. 346-580. 1899.

Spurr, J. E., The iron-bearing rocks of the Mesabi range in Minnesota: *Geol. and Nat. Hist. Survey of Minn., Bull.* no. 10. 1894.

[33] Leith, C. K., *op. cit.*, pp. 202-204.

In more recent reports on the geology of the Lake Superior district by Van Hise and Leith,[35] prepared since the discovery of iron-bearing formation and iron ore in the Cuyuna district, the slates and schists of east central Minnesota are all classified as upper Huronian and are correlated with the Virginia slate of the Mesabi district. The slates occurring along St. Louis and Kettle rivers, the schists and associated metamorphosed rocks of the Cuyuna district, and the slates and schists found along Mississippi River near Little Falls are all believed to be more or less equivalent. The iron-bearing formation of the Cuyuna district is called the Deerwood iron-bearing member and is described as occurring in beds and lenses in the lower part of the Virginia slate. The base of the slate, however, is not known anywhere in eastern or central Minnesota, so that the underlying formations, whatever they may be, have not been discovered. The granite, gneiss, and other igneous rocks of central Minnesota which had previously been regarded as lower Huronian or Archean, are in this report classified as Keweenawan on account of their supposed intrusive relation to the upper Huronian slates.

Outside of east central Minnesota but few changes were made in the classification of the rocks. The Giants Range granite, however, and various highly metamorphosed sediments of the Mesabi and Vermilion districts which had hitherto been included in the lower Huronian are reclassified as lower-middle Huronian to correspond with the lower and middle Huronian of northern Michigan.

---

[34] Spurr, J. E., The stratigraphic position of the Thomson slates: *Amer. Jour. Sci.*, 3d ser., vol. 148, pp. 159-166. 1894.

[35] Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: *U. S. Geol. Survey, Mon.* 52, pp. 211-224. 1911.

................................, Pre-Cambrian rocks of North America: *U. S. Geol. Survey Bull.* 360, pp. 196-252. 1909.

GENERAL DISTRIBUTION AND LITHOLOGY OF THE ROCKS

A heavy mantle of glacial till covers the older rocks throughout east central Minnesota, obscuring their distribution and their relations to each other. Only here and there isolated masses of the underlying rocks project up through it. Such projections are mainly of harder rock, which formed hills and ridges above the general level of the surface on which the glacial material was deposited. Locally also the rivers have cut down through the glacial drift and exposed the underlying rock. Outcrops of bed rock are closely spaced in parts of Stearns, Sherburne, Benton, Morrison, Mille Lacs, Kanabec, Pine, and Carlton[36] counties, but in other counties, among them Crow Wing, Todd, Cass, and Aitkin, rock exposures are either entirely lacking or are relatively rare.

In the east central part of Minnesota, as has been mentioned, the bed rock consists mainly of ancient metamorphosed pre-Cambrian rocks. Paleozoic and Mesozoic rocks do not cover large areas. Probably they never extended over the entire area and where they were deposited they were nearly everywhere removed by erosion before the advent of the glacial epoch. Some Paleozoic rocks, however, occur in the area traversed by the lower courses of St. Croix and Rum rivers, and outliers of Mesozoic sediments are present in many places in the region traversed by Mississippi River.

The boundary between the pre-Cambrian rocks on the west and northwest and the Paleozoic rocks on the east and southeast, trends a little east of north through the south central part of the State, and continuing northward crosses Mississippi River into the southeastern part of Sherburne County. From there the boundary continues in the same general northeast direction to the upper St. Croix River, but its location has not been definitely established. As already stated, the Keweenawan sediments which extend southwestward from the west end of Lake Superior are very similar lithologically to the sediments forming the lower part of the Paleozoic, and have not as yet been separated from them in this region. Fossiliferous Paleozoic sediments have been identified as far north as the southern part of Pine County, while sediments classed as upper Keweenawan[37] are definitely known as far south as the southern part of Carlton County, and probably they extend some distance farther. Numerous outcrops of red, pink, and white sandstone occur in eastern Kanabec and western Pine counties, but since fossils have not been found at any of these localities it has not been possible to determine the age of these rocks. There is thus in east central Minnesota an area of sandstone of undetermined age between the northernmost known Paleozoic sediments and the southernmost known sediments of supposed upper Keweenawan age.

---

[36] Hall, C. W., Keewatin area of eastern and central Minnesota: *Geol. Soc. America Bull.* vol. 12, pp. 343-376. 1901.

Upham, Warren, Notes on rock outcrops in central Minnesota: *Geol. and Nat. Hist. Survey of Minn., Eleventh Ann. Rept.*, pp. 86-136 and Pl. I. 1882.

[37] Thwaites, F. T., Sandstones of the Wisconsin coast of Lake Superior: *Wis. Geol. and Nat. Hist. Survey Bull.* 25. 1912.

The Paleozoic sediments in the southern part and the Keweenawan sediments and igneous rocks in the northern part of east central Minnesota form the eastern margin of an extensive area of pre-Cambrian metamorphosed sediments and igneous rocks. On the west, these older, metamorphosed rocks are covered by nearly flat-lying, partly consolidated Cretaceous sediments. The eastern limit of the main Cretaceous area is west of Mississippi River. The boundary is a very irregular one, patches of Cretaceous rock occurring in many places within the area of older rocks both east and west of Mississippi River.

The following is a tentative section of the rocks of east central Minnesota, essentially that employed by the United States Geological Survey.[38]

Section of Rocks for East Central Minnesota

- *Quaternary*
  - Recent
    - Alluvium
  - Pleistocene
    - Late Wisconsin till
    - Early Wisconsin till
- *Cretaceous*
  - Yellow and gray clay and sand, in part calcareous
  - Ferruginous conglomerate
- *Cambrian*
  - Upper Cambrian
    - Sandstone and shale
- *Algonkian*
  - Keweenawan
    - Intrusives. Granite, syenite, diorite, diabase, and gabbro
    - Pink and red sandstone and arkose
    - Volcanic flows. Amygdaloid, tuff, breccia, and diabase
  - Huronian
    - Upper Huronian (Animikie group)
      - Virginia slate (including "St. Louis" slate and slates and schists of Cuyuna Range and Little Falls area)—quartzitic, carbonaceous, micaceous, chloritic, amphibolitic, garnetiferous, and staurolitic schist and slate with lenses of graywacke, quartzite, grit, limestone, and Deerwood iron-bearing member, with which are associated masses of metamorphosed subsilicic igneous rocks

---

[38] Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: *U. S. Geol. Survey Mon.* 52, pp. 595-626 and 211-224. 1911.

Lower-middle Huronian (possibly present)
    Granite (equivalent to Giants Range granite)
Archean **(possibly present)**
    Granite and gneiss

No rocks of undoubted Archean age occur in east central Minnesota. There are, however, in Cass, Todd, Morrison, Stearns, Sherburne, Benton, Mille Lacs, Kanabec, Aitkin, and Pine counties, numerous outcrops of granite and gneiss the age of which has not been definitely determined. Some of the granite in the eastern part of this area is intruded into schist believed to be of upper Huronian age and is therefore, post-upper Huronian. Other granites, especially those in the western part of the area, give some indication of being lithologically and areally related to the lower-middle Huronian Giants Range granite of the Mesabi district.

Besides these, however, there are many outcrops of coarse gneissoid granite, banded gneiss, and augen-gneiss which resemble the Archean rocks more closely than any of the later intrusives. Banded gneisses and gneissoid granites are prominently exposed on Hillman Creek and Skunk River in Morrison County, on Rum River in Mille Lacs County, and along the Minneapolis, St. Paul, and Sault Ste. Marie Railway west of Denham and elsewhere in Pine County. Augen-gneiss occurs in a series of outcrops near McGrath and Arthyde in Aitkin County, and near Denham in Pine County.

Outcrops of subsilicic igneous rocks are also found in east central Minnesota, but less abundantly than those of silicic rocks, and most of them represent intrusions into the upper Huronian schists. They are, therefore, probably related to the subsilicic intrusives of Keweenawan age which occur so abundantly north and south of Lake Superior. In a number of places, however, outcrops of subsilicic rock occur of which the relationship is not clear. This is especially true of the diabase and diorite exposures occurring along the shores of Long Lake in Aitkin County and at various localities in Carlton County. Winchell[39] correlated the rocks cropping out at Long Lake with the Keewatin greenstone of the Vermilion district in northern Minnesota, while Van Hise and Leith[40] have classified them as Keweenawan. Recent exploration in the Cuyuna district, however, has shown that similar rocks occur both intrusive into and interbedded with upper Huronian schists in this district. It has been found also that many of these rocks have suffered considerable dynamic metamorphism. Therefore it seems probable that subsilicic rocks of upper Huronian as well as Keweenawan age occur in east central Minnesota, but the existence of Archean subsilicic igneous rocks in this region seems doubtful.

---

[39] Winchell, N. H., The Cuyuna iron range. *Econ. Geology*, vol. 2, pp. 565-571. 1907.
[40] Van Hise, C. R., and Leith, C. K., *op. cit.*, Pl. I.

There is thus considerable uncertainty as to whether Archean rocks are found in east central Minnesota. Since, however, the age of most of the silicic igneous rocks in this region has not been determined and since rocks similar to those which exist here are known to occur in the areas of Archean rocks in the southwestern and northern parts of the state, it does not seem improbable that some of the silicic intrusive rocks of east central Minnesota are of Archean age.

No rocks of known lower or middle Huronian age have been found in east central Minnesota. The granite outcrops of Cass and Todd counties, which will be described later, present certain similarities, however, to the Giants Range granite of the Mesabi district and may be continuous with it. This view is supported by the fact that granite has been encountered in drilling at several localities between the western end of the Mesabi district and the Cass and Todd county outcrops. Among the other outcrops of silicic igneous rocks of undetermined age in east central Minnesota many may be of lower-middle Huronian age as well.

The most interesting rock exposures of east central Minnesota as regards structure and correlation are those of metamorphosed sediments which occur in various parts of the region and which have been classed as upper Huronian or Animikie in age. The most important of these are the slate, graywacke, phyllite, and mica schist outcrops occurring along St. Louis and Kettle rivers in Carlton and northern Pine counties, the quartzite outcrops at Dam Lake, south of Kimberly, Aitkin County, and the slate, phyllite, and mica, staurolite and chlorite schist outcrops occurring along Mississippi River and a few of its branches in Morrison County. Drilling and mining operations in the Cuyuna iron-ore district have shown the presence of an extensive area of metamorphic rocks, covered by glacial drift in central Crow Wing and western Aitkin counties. Most of the metamorphosed rocks which have been found in east central Minnesota are of sedimentary origin, but some of them have a structure, distribution, and general character that strongly suggest an igneous origin.

The outcrops in Carlton and Pine counties consist mainly of slate, graywacke, phyllite, and mica and hornblende schists. Slate, graywacke, and phyllite occur in the northern part, at Carlton and Cloquet, while to the south phyllite and coarse mica schist occur near Moose Lake and northeast of Denham, and hornblende schist is found at several localities along Kettle River west of Moose Lake. South of Denham, near the southern edge of the main region of metamorphosed sediments, there occurs a series of interbedded mica and amphibole schist, quartzite, grit, and crystalline limestone which is bounded on the south by an extensive area of gneiss. The strike of the sedimentary structures throughout this region is approximately east and west, while the dips vary on each side of vertical.

The detailed work on the outcrops of Pine and Carlton counties is not yet completed and the general structure has not been definitely determined. The rocks appear to lie in a series of east-west trending folds with horizontal or slightly eastward or westward pitching axial lines. Probably the predominating pitch of the folds is to the east indicating that to the west rocks of lower stratigraphic horizons may be expected to occur. The largest folds found up to the present have a width of several miles and numerous minor folds down to fine crenulations occur on their limbs.

The quartzite outcrops at Dam Lake consist of light gray to pink quartzite. They show no bedding or secondary structures by which their relation to the other rocks of central Minnesota might be determined.

The schist and slate outcrops along Mississippi River grade from finely micaceous slate and phyllite near Little Falls to coarsely crystalline, garnetiferous and staurolitic biotite schist in the southern part of Morrison County. Where it is possible to distinguish the bedding as at the mouth of Little Elk River, and at Little Falls, the strike of the rocks is in general northeast-southwest. The dips vary due to undulatory folding.

Northwest of Little Falls near Randall several areas of outcrops consisting of chloritic schist occur not far from Little Elk River, 8 to 10 miles above its mouth. These rocks have the same strike as the slate beds of Little Falls, and apparently form a belt running parallel to and northwest of the slate belt.

No connection has been demonstrated between the slate and mica schist near Little Falls and that occurring near Carlton and Moose Lake. As they are found approximately along the same general line of strike, however, it is possible that they may be continuous. This view is somewhat strengthened by the fact that, in recent exploration work in the Cuyuna district, the chloritic schist occurring at Randall has been shown to continue northeastward through Crow Wing County and for some distance into Aitkin County. If the slate and mica schist belt follows along parallel to the chloritic schist belt and southeast of it, as might be expected, this would bring it to within a comparatively short distance of the exposures at Moose Lake and Carlton. Drilling in T. 45N., R. 24W., about 10 miles east of the north end of Mille Lacs Lake has shown the presence of mica schist in this intervening area.

The relation of the slate, phyllite, and schist of east central Minnesota to the Virginia slate in the Mesabi district has not been determined.

As regards the metamorphism and deformation which they have suffered, the contrast between them is great. While the Virginia slate has a gentle dip to the south and shows little or no secondary cleavage, being practically an indurated shale, the slate and schist of east central Minnesota have been closely folded and highly metamorphosed so that cleavage is developed throughout, and locally the mineral constituents have been coarsely recrystallized. Van Hise and Leith, however, believe that the Virginia slate continues southward from the Mesabi district into east central Minnesota where it is represented by these metamorphosed phases. But since no rock outcrops are known for at least 40 miles south of the Mesabi district, certain correlation is difficult. It is not impossible that the schist and slate of east central Minnesota are of middle or lower Huronian age. In their general character and in the deformation which they have suffered they resemble the older rocks very closely.

The metamorphosed sediments have been intruded by both silicic and subsilicic igneous rocks in many parts of east central Minnesota. Subsilicic rocks, such as gabbro, diabase and diorite, are especially common in the western portion. Silicic rocks such as biotite granite, occur more abundantly in the eastern portion. The igneous rocks are in the form of dikes, bosses, and irregular masses. Since the metamorphosed sediments are believed to be of upper Huronian age, these intrusives have been designated as Keweenawan. They are believed to be the vents through which were poured out the lavas that at present occupy the valley of the upper St. Croix River and which in former times probably extended westward over a considerable portion of east central Minnesota.

There are a number of localities in east central Minnesota where subsilicic igneous rocks which have suffered considerable dynamic metamorphism occur. These, as has been mentioned, are believed to be older than Keweenawan, being associated with the upper Huronian metamorphosed sediments and probably representing contemporaneous flows or slightly younger intrusive masses. They have been deformed and metamorphosed with the associated sediments.

The Keweenawan rocks occuring along the upper St. Croix River are mainly of the subsilicic extrusive type, including diabase, diabase amygdaloid, tuff, and breccia.[41] Interlayered with these are local beds of conglomerate. A general characteristic of the lava beds is that each bed consists of three texturally distinct phases of rock. The lower few inches usually consist of dense, finely crystalline, finely shattered rock. Above this is the main mass of the flow which is usually medium coarsely crystalline, distinctly ophitic in texture, and is free from amygdules or other cavities. The crystalline phase grades upwards into an amygdaloidal portion which represents the surface of the flow. Locally the upper portions of a flow may be tuffaceous or brecciated, while in other places important layers of volcanic clastic rocks are interbedded between successive flows. The coarseness of crystallization of the main mass of the flow depends largely on the thickness. Some of the more extensive flows, which range up to two hundred feet in thickness, are fairly coarsely crystalline.

---

[41] Grout, F. F., Contributions to the petrography of the Keweenawan: *Jour. Geology*, vol. 18, pp. 633-657. 1910.

Hall, C. W., Keweenawan area of eastern Minnesota: *Bull. Geol. Soc. America*, vol. 12, pp. 313-342. 1901.

Berkey, C. P., Geology of the St. Croix dalles: *Amer. Geol.*, vol. 20, pp. 345-383, 1897, and vol. 21, pp. 139-155 and 270-294, 1898.

The conglomerate layers are usually thin and are very local in their occurrence. At several localities, however, beds as thick as one hundred feet have been reported.[42]

The St. Croix area of Keweenawan lavas is delimited on the west by a fault which extends northeastward toward Lake Superior, forming the boundary between the eastward dipping Keweenawan lavas, on the southeast, and the horizontally bedded, non-fossiliferous sandstone of supposed upper Keweenawan age, already mentioned, on the northwest. Because of this fault it has been impossible to determine the relation which these two formations bear to each other.

In many places in eastern Minnesota outcrops of horizontally bedded sandstone, designated as "Hinckley sandstone," "Potsdam sandstone," and "St. Croix sandstone," have been reported by geologists of the early Geological and Natural History Survey of Minnesota.[43] The outcrops designated as "Hinckley sandstone" or "Potsdam sandstone" are for the most part non-fossiliferous, and, as has been mentioned, many of these probably are to be correlated with the Bayfield group of the upper Keweenawan. In the southern part of the region, however, especially along St. Croix River, there are numerous outcrops of fossiliferous sandstone designated as "St. Croix sandstone," which are probably equivalent to certain of the lower formations of the Upper Cambrian. Fossiliferous sandstones are found along St. Croix River as far north as Rush Creek, a short distance below the mouth of Snake River. Similar flat-lying sediments in which, however, fossils have not been found, occur for some distance north of this point, continuing beyond the mouth of Kettle River.

---

[42] Hall, C. W., *op. cit.*, pp. 326 and 329.

[43] Upham, Warren, The geology of Mille Lacs and Kanabec counties: *Geol. and Nat. Hist. Survey of Minn.*, vol. 2 (Geology) 1882-1885, pp. 612-628. 1888.

Upham, Warren, The geology of Chisago, Isanti, and Anoka counties: *Geol. and Nat. Hist. Survey of Minn.*, vol. 2 (Geology) 1882-1885, pp. 399-425. 1888.

Upham, Warren, The geology of Pine County: *Geol. and Nat. Hist. Survey of Minn.*, vol. 2 (Geology) 1882-1885, pp. 629-645. 1888.

Winchell, N. H., The geology of Carlton County: *Geol. and Nat. Hist. Survey of Minn.*, vol. 4 (Geology) 1896-1898, pp. 1-24. 1899.

Upham, Warren, The geology of Aitkin County: *Geol. and Nat. Hist. Survey of Minn.*, vol. 4 (Geology) 1896-1898, pp. 25-54. 1899.

Winchell, N. H., The geology of the southern portion of St. Louis County: *Geol. and Nat. Hist. Survey of Minn.*, vol. 4 (Geology) 1896-1898, pp. 212-221. 1899.

There is thus along St. Croix River an area of flat-lying sandstone which toward the south contains fossils of Upper Cambrian age. This area is bounded on the west by steeply eastward dipping Keweenawan flows with interlayered conglomerate. Beyond the volcanic rocks, separated from them by a fault, is another belt of flat-lying sandstone, which, however, is non-fossiliferous. It has generally been supposed that these two sandstones are of approximately the same age, and hence they have usually been mapped as one formation. More recent study, however, indicates that eventually a separation may be made between them, throwing the non-fossiliferous sandstone into the Keweenawan.

Slightly consolidated Cretaceous sediments are known to occur at a number of localities in east central Minnesota. Exposures are found at a few places south of Little Falls along Mississippi River and west of it, while in the Cuyuna district these rocks have been encountered in drilling and mining operations. The exposures along Mississippi River consist principally of sandy and calcareous clay. Some portions are slightly consolidated, while other portions are quite soft. Locally beds occur containing little ferruginous concretions. The Cretaceous rock encountered in exploration work in the Cuyuna district is principally ferruginous conglomerate and shale.

DESCRIPTIONS OF ROCK OUTCROPS

OUTCROPS OF SILICIC IGNEOUS ROCKS

SOUTHERN CASS, TODD, AND WESTERN STEARNS COUNTIES

The westernmost outcrops of silicic igneous rocks in central Minnesota are those occurring in the southwestern corner of Cass County, northeast of Staples, those occurring near Long Prairie River south of Staples in Todd County, and those occurring in the vicinity of Sauk Center and Melrose, and in Ashley township, in the western part of Stearns County.

The exposures northeast of Staples are scattered over a prominent ridge north of Crow Wing River, and occupy an area about half a mile long. The principal rock of these exposures is a pink to greenish, light-colored, medium-grained hornblende granite. In some phases of it, quartz and feldspar are almost equally abundant, but in other phases quartz is exceedingly rare and the rock grades into syenite. In this respect it resembles the Giants Range granite of the Mesabi district. The principal ferromagnesian mineral is green hornblende, but biotite is present in some phases. The granite is intruded by dikes of dark green rock of intermediate composition. The dikes are fine-grained along the contacts but are medium-grained in the center. They vary in thickness up to thirty or forty feet. Both the granite and the green dikes are strongly epidotized.

The group of outcrops in Todd County is located in the west township of Ward about 1 mile west of Long Prairie River, and about 5 miles northeast of Browerville.[44] There are several exposures. The rock is described by Upham as a medium-grained gray syenite consisting mainly of quartz, feldspar, and dark hornblende. It is somewhat similar to the rock found northeast of Staples and resembles it also in being epidotized.

In the northwestern part of Stearns County three groups of outcrops occur near the towns of Sauk Center and Melrose, and in the township of Ashley. The outcrops in Ashley township consist of numerous exposures south of Ashley Creek.[45] The rock resembles syenite but has been strongly epidotized so that no hornblende or mica remains, and it consists mainly of feldspar and epidote. The Sauk Center outcrops are found a short distance southeast of the depot. Several varieties of rock occur, the principal one being a feldspathic reddish gneiss, laminated in a northeast-southwest direction. Associated with the gneiss are reddish syenite and masses of pink quartz-feldspar pegmatite. Several exposures of a hard, dark, granular hornblende feldspar rock occur, probably syenite. The outcrops at Melrose are within the village, south of Sauk River. They consist of hard, coarse, red syenite. In the western part of the village a well is said to have been sunk in a dark, coarsely crystalline hornblende rock.[46]

In the eastern part of Cass County, southeast of Leech Lake, drilling has shown the occurrence of granite in three localities along a line running southwestward from the western end of the Mesabi district. This rock has been mapped by Van Hise and Leith[47] as Giants Range granite and is supposed to be continuous with that in the Mesabi district. On the other hand, the granite outcrops at Staples, as well as numerous other outcrops to the south and southeast, have been mapped by them as Keweenawan on the supposition that they are intrusive into the upper Huronian schist and slate. However, this intrusive relation has been definitely established for only a few of the outcrops of silicic igneous rocks in central Minnesota, and since lithologically the Cass County and Todd County outcrops resemble the Giants Range granite it is not impossible that they may be of the same age, viz., lower-middle Huronian.

---

[44] Upham, Warren, The geology of Wadena and Todd counties: *Geol. and Nat. Hist. Survey of Minn., Geol. of Minn.*, vol. 2, 1882-1885, pp. 568-569.

[45] Upham, Warren, The geology of Stearns County: *Geol. and Nat. Hist. Survey of Minn., Geol. of Minn.*, vol. 2, 1882-1885, pp. 452-454.

[46] Upham, Warren, *op. cit.*

[47] Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: *U. S. Geol. Survey Mon.* 52, Plate I.

MORRISON COUNTY

In Morrison County outcrops of silicic igneous rocks are abundant, especially in the central and eastern part, east of Mississippi River. The principal exposures occur in an area approximately 18 miles long, east and west, and 12 miles wide north and south, but small isolated outcrops are found outside of this area.

Several small exposures of medium to coarse-grained syenite are found on the east bank of Mississippi River in Little Falls, about a quarter of a mile below the dam and approximately opposite the lower part of the island which occurs in the river at this place. The rock consists of hornblende and feldspar, the former locally altered in part to epidote and the latter to zoisite, epidote, muscovite, and quartz. Some quartz and biotite occur in the rock also. Locally chlorite is found as an alteration product of biotite and hornblende. Apatite and titanite are accessory minerals. The occurrence of this igneous rock within a short distance of the slate and phyllite outcrops at the dam and on the island would seem to indicate that it is intrusive into the sedimentary rocks. No actual contacts, however, have been found.

An important group of granite and gneiss outcrops is that occurring in the eastern part of Morrison County on Platte River, Skunk River, and Hillman Creek. In general these are of gray and pink biotite and hornblende granites, locally somewhat gneissoid in texture. A few outcrops of banded gneiss are found.

The northernmost of these outcrops is a group of exposures occurring on both sides of the east-west township road between section 34, T. 42N., R. 31W., and section 3, T. 41N., R. 31W. Two types of granite occur in these exposures, a medium fine-grained grayish brown or brown decomposed biotite granite, considerably epidotized, and a grayish pink or pink hornblende granite. The former has a fairly uniform grain, but the latter varies in texture from fine-grained to very coarse-grained, almost pegmatitic, and also shows porphyritic phases. The hornblende granite appears to be intrusive in the biotite granite.

In the northwest corner of section 1, T. 41N., R. 31W., and the southwest corner of section 36, T. 42N., R. 31W., about 1½ miles east of the outcrops just described, and one mile north of Freedhem, there are a number of exposures of fine-grained, dark gray, biotite granite mixed with a pinkish, medium to coarse-grained granite which usually contains both biotite and hornblende. From the relations it appears that the pink granite is intrusive as dikes and irregular masses into the dark gray granite which is by far the more abundant. The pink granite contains much pink feldspar while the dark gray granite is rich in quartz and biotite. The rocks crop out in a swamp both north and south of the township road.

Near the center of section 6, T. 41N., R. 30W., about 1½ miles south of east from the outcrops just described, are a few scattered outcrops consisting principally of fine to medium-grained, dark gray biotite granite, rich in quartz, which is intruded by dikes of coarse-grained, pink biotite granite. In general the rocks resemble those occurring one mile north of Freedhem but apparently little or no hornblende is present in the pink granite.

A group of exposures of considerable extent occurs north and south of the section line between sections 7 and 18, T. 41N., R. 30W., some distance east of the quarter post. It is located about 1½ miles south of the outcrops in section 6. Two kinds of rock are present, (1) a dark gray, fine to medium-grained biotite granite, and (2) a medium to coarse-grained pink biotite granite. There is a sharp line of division between these two types marked approximately by a diagonal road which cuts across the two sections in a northeast-southwest direction. To the southeast of the road the outcrops are of pink granite, while to the northwest they are of dark gray granite. The pink granite is found also as small irregular intrusions in the gray granite. A small quarry occurs in the area of the gray granite. The dark gray granite consists of fresh, glassy, colorless feldspar and quartz with abundant biotite and some hornblende. Locally hornblende predominates over biotite. The hornblende in places is slightly altered to epidote and the biotite to chlorite. The pink granite consists mainly of pink feldspar and biotite, but quartz is present in small amounts.

In sections 23 and 24, T. 41N., R. 31W., about 1½ miles north of the locality known as Gravelville, and about 2 miles southwest of the outcrops just described, a large number of granite exposures occur in an area of about one square mile. The principal exposures form a prominent ridge surrounded on three sides by low marshy areas. Some smaller exposures occur within the marshy areas. Several types of granite are present, the principal one being a dark gray, medium-grained granite with abundant hornblende and considerable biotite. Next to this in abundance is a coarse pink biotite granite which seems to be intrusive into the hornblende granite, but which since intrusion has suffered deformation. Besides these types a fine-grained black granite occurs which contains both hornblende and biotite, the former epidotized, while a fourth type consists of fine-grained pink biotite granite, in places porphyritic. These various types are irregularly intermixed and grade into each other. The medium-grained, dark gray hornblende granite is much more abundant than the other phases. At one point a small quarry occurs in it and here the rock is quite fresh, showing only a slight alteration of the ferromagnesian minerals to epidote and chlorite. The pink granites appear to be intrusive into it, although the occurrence is very irregular. The coarse and fine-grained varieties of pink granite have a similar mineral composition and are probably phases of the same rock. They contain little or no hornblende. The fine-grained black granite is not very abundant. It occurs mainly in the form of irregular included masses in the hornblende granite.

A considerable number of outcrops of silicic igneous rocks occur on Skunk River and Hillman Creek, east of Little Falls. The area through which the outcrops are scattered is about 15 miles long in a northeast-southwest direction, and about 6 miles wide. The town of Pierz is in the southwestern part of the area. Most of the outcrops occur on the streams or within a short distance from them. As a rule the rocks do not rise far above the surface of the soil and in a few localities they have been exposed only by quarrying.

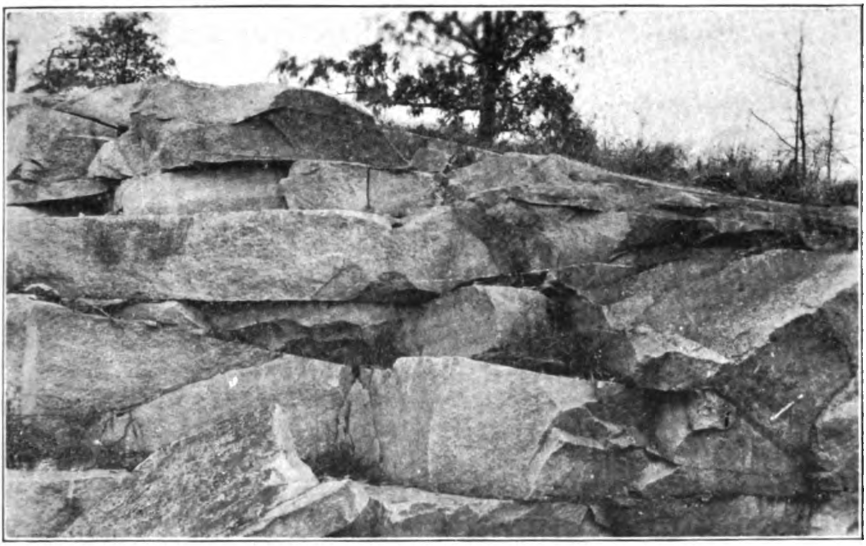
The westernmost of these outcrops is at Meyer's quarry south of Fish Lake and about a mile west of the station of New Pierz. A very uniform, fine-grained, light gray, biotite granite occurs here and some of it has been quarried. There are no outcrops other than those in the quarry.

Several other granite outcrops are found not far from the village of Pierz, one occurring on Skunk River near the station of New Pierz, another one near the junction of Hillman Creek with Skunk River east of Pierz, and a third one along the Minneapolis, St. Paul, and Sault Ste. Marie railroad, about 2½ miles east-northeast of the station of New Pierz.

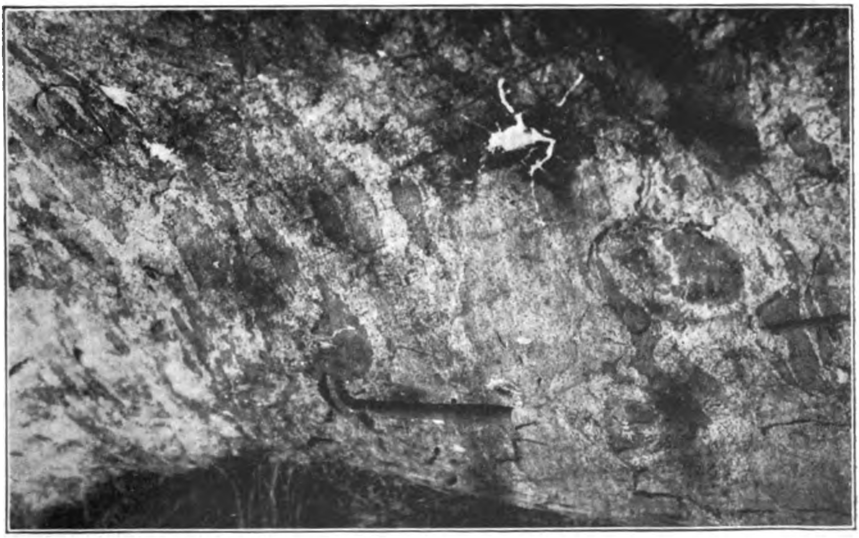
The first of these is an outcrop of medium-coarse, light gray, biotite granite, about 50 feet long and 60 feet wide. It is situated about a fifth of a mile southeast of the railroad station on the east bank of Skunk River.

The second outcrop is located on the south side of Skunk River about a fourth of a mile above the mouth of Hillman Creek. Several exposures of gray, banded biotite gneiss are found here. Most of the rock is fine-grained and dark, but layers of coarse-grained, light-colored rock occur interbanded with the fine-grained rock. Disseminated crystals of garnet similar to those occurring in the gneiss at Granite City, farther up Skunk River, are abundant. At one point a dike of medium-coarse grained pink syenite cuts the gneiss.

The third one of the outcrops near Pierz occurs in a railroad cut near the west side of section 10, T. 40N., R. 30W. The rock is mainly light



A. GRANITE OUTCROP AT MEYERS QUARRY NEAR PIERZ, MORRISON COUNTY, SHOWING HORIZONTAL JOINTING
PHOTO BY CARL ZAPPFE



B. INCLUSIONS OF DARK GRAY GRANITE IN PINK GRANITE AT GRAVELVILLE, MORRISON COUNTY

UNIV. OF MICH.

to dark gray, medium coarse-grained biotite granite. Locally it shows a marked gneissoid texture due to the parallel arrangement of biotite flakes and their segregation along certain bands. Small dikes of light-colored aplite cut the granite.

Besides these another outcrop of granite is mentioned by Upham[48] as occurring in the southwestern part of section 22, T. 40N., R. 30W. The rock is said to have been quarried. No indications of this outcrop, however, were found by one of the writers (Johnston) who visited the locality.

About 8 miles up Skunk River, northeast of Pierz, is a locality known as Granite City where a saw mill and village existed previous to the Indian outbreak of 1862. Outcrops of coarse-grained gray granite and of gray and white banded gneiss occur at this place on both sides of the river. The granite contains quartz, biotite, and white feldspar in approximately equal amounts. Locally the feldspar predominates, however, and occurs in somewhat larger grains, so that it gives the rock a porphyritic appearance. In places the biotite shows a tendency to parallel arrangement, thus giving gradations into gneiss. Dikes of medium fine-grained aplite are found in several places in the granite.

The gneiss occurs as bands bounded by granite. It consists of interlayered fine and coarse-grained material. The coarse-grained layers consist mainly of quartz and feldspar and are usually white or light-colored, while the fine-grained layers contain abundant biotite and are dark gray. At many places the fine-grained layers show fine lamination due to the parallel arrangement of biotite. Locally also they contain fine, light-colored laminae of fine-grained feldspar, or quartz and feldspar. The dark and light-colored layers in the gneiss vary in thickness up to perhaps an inch or more, the dark fine-grained layers being thicker and making up more of the rock. Red garnet is abundant locally in the gneiss, usually occurring in the fine-grained layers as scattered crystals. Hornblende does not occur ordinarily as a constituent either in the granite or gneiss, but locally it is found in the latter in large crystals scattered through certain layers similarly to the garnet.

In the NE¼ of the SW¼ of section 11, T. 41N., R. 29W., about 3 miles northeast of the Granite City locality just described, a small outcrop of granite occurs in the road. The rock consists of fine to coarse-grained gray biotite granite similar to that at Granite City, and contains a few small lenses of pegmatitic material. No gneiss occurs in this outcrop.

In the SW¼ of section 12, T. 41N., R. 29W., at a locality known as Rucker, several small outcrops of rock are found along the west side of Skunk River. Most of the exposures consist of a dark lavender or greenish gray hornblende rock. It has a porphyritic texture, containing phenocrysts of hornblende and gray calcic feldspar, the former predominating. The hornblende has a granular appearance rather than the usual fibrous texture. The rock is probably a syenite or diorite.

---

[48] Upham, Warren, The geology of Crow Wing and Morrison counties: *Geol. and Nat. Hist. Survey of Minn., Geol. of Minn.*, vol. 2, 1882-1885, pp. 580-611.

At this locality one exposure occurring southwest of the bridge over Skunk River consists of coarse-grained, dark gray, biotite granite, cut by dikes of medium to coarse-grained pink granite. The gray granite is fresh in appearance due to the presence of abundant fresh, colorless or white feldspar. Biotite is abundant in it and some hornblende occurs. The pink granite consists mainly of pink feldspar, but it contains abundant quartz and everywhere a little biotite. The feldspar shows very irregular crystallization, masses of fine-grained and coarse-grained material being closely associated.

A small knoll consisting of gray and pink granite occurs on the north side of Little Skunk River near the east side of section 6, T. 41N., R. 28W., about 2 miles above Rucker. The gray granite is a coarse-grained biotite granite, similar in appearance to that at Granite City. It contains frequent scattered crystals of hornblende, some of them more than half an inch long. The pink granite varies in texture and composition. Some phases of it are coarse-grained and almost free from ferro-magnesian minerals, while other phases are medium-grained and contain abundant scattered biotite. Frequently the coarse and medium-grained types are closely associated. A few small dikes of fine-grained, light-colored granite are intruded into the gray granite.

Several other rock outcrops occur on Little Skunk River and on the upper portion of Skunk River, both in section 6, T. 41N., R. 28W., and in section 1, T. 41N., R. 29W. One of the larger ones of these is found near the center of section 1 and consists of granite. Another one is mapped by Upham[49] as occurring along the northern boundary of section 6. The latter, however, could not be found and has probably been confused with the outcrop at Rucker as is indicated by the description.

An interesting group of exposures of various kinds of granite is found along Hillman Creek and Little Hillman Creek in an area about 3 miles long east and west, and about 1 mile wide. The westernmost of these outcrops occur about 4½ miles east of Pierz in the eastern part of section 7 and western part of section 8, T. 40N., R. 29W. They form an elevation along the north side of Hillman Creek and consist of coarse gray biotite granite which is intruded by medium-grained pink biotite granite. The gray granite locally is porphyritic and contains conspicuous crystals of white feldspar, but for the most part it is even-grained. The pink granite shows pegmatitic facies locally, while elsewhere it is intruded as narrow dikes and is fine-grained.

---

[49] Upham, Warren, The geology of Crow Wing and Morrison counties: *Geol. and Nat. Hist. Survey of Minn., Geol. of Minn.*, vol. 2, 1882-1885, Pl. 53 and p. 592.

In the northeastern part of section 8, fine-grained pink and dark gray granites are intruded into coarse pinkish gray granite. The Minneapolis, St. Paul, and Sault Ste. Marie railroad cuts through two of the outcrops and two small quarries occur in them, one to the north and one to the south of the railroad. The fine-grained pink granite consists mainly of pink feldspar and quartz, but biotite and hornblende occur scattered through it. The fine-grained, dark gray granite contains abundant ferromagnesian minerals, both biotite and hornblende. It is not extensive areally. The coarse-grained gray granite covers a larger area than the other two types. It is fresh and consists of slightly pinkish feldspar and quartz with much biotite. The latter is partly altered to chlorite. The pink granite intrudes it as dikes and as larger intrusive masses. Pink pegmatitic phases occur also. The quarries are both in the pink granite.

Farther up Hillman Creek, in section 35, T. 41N., R. 29W., about a mile above the locality just described, are the remains of an old logging dam. At this place a large number of outcrops occur on both sides of the creek and extend for some distance to the north. The Minneapolis, St. Paul, and Sault Ste. Marie railroad has cut through one of the larger outcrops. Most of the exposures south of the creek consist of coarse-grained gray granite with some gneissic phases, while those to the north are mainly fine-grained pink granite. The pink granite contains only a small amount of ferromagnesian minerals, being composed principally of pink feldspar and quartz. It is intruded into the coarse gray granite as dikes and large masses. In the railroad cut a nearly horizontal sill of pink granite varying up to two feet in thickness, and bounded above and below by coarse gray granite, occurs in both walls of the cut almost along the entire length. North of Hillman Creek, the intrusive masses of pink granite are much larger, though the texture is uniformly fine-grained. The coarse gray granite is a biotite granite similar to that already described as occurring to the southwest. Portions of it apparently have suffered considerable deformation and recrystallization with the result that masses of coarse banded gneiss have developed. These, however, are of restricted occurrence. Not all the dikes are of pink granite. There are also dikes of fine-grained gray biotite granite which cut the coarse-grained granite. One of these is exposed in the railroad cut.

On Little Hillman Creek in section 9, T. 40N., R. 29W., about a mile east of the outcrops in sections 7 and 8, there is another group of exposures of gray and pink granite. The principal rock is a coarse-grained biotite granite, in general having a gray appearance, but in places containing pink feldspar in abundance. This rock is intruded by dikes of fine-grained light gray and dark gray granite and fine-grained white to pink aplite. The light gray granite contains but a small amount of ferromagnesian minerals, while the dark granite contains abundant biotite and some hornblende. The aplite dikes are in places made up almost entirely of quartz and pink feldspar. Locally, however, scattered ferromagnesian minerals are present. The gray coarse granite has suffered deformation and in places shows gneissic structure.

A few small outcrops consisting mainly of very coarse-grained pink biotite granite are found near the west side of section 18, T. 39N., R. 30W., about three miles southwest of Buckman. They occur in a barnyard a short distance from the north-south township road. The rock is considerably weathered and friable. It contains inclusions of a fine-grained dark gray rock. One of the outcrops consists of fresh pink granite with texture varying from fine-grained to coarse-grained in different parts.

STEARNS, BENTON, SHERBURNE, AND WESTERN MILLE LACS COUNTIES

The region surrounding Saint Cloud and Sauk Rapids contains a large number of rock outcrops, principally granite and subordinately diorite and gabbro. They are situated mainly in the eastern part of Stearns County and in the western parts of Benton and Sherburne counties, and extend approximately from Watab on the north to Linden township on the south, and to Rockville on the southwest. The area in which outcrops occur is about 16 miles long north and south, and about 12 miles wide. Outside of this area, however, there are a few scattered outcrops, such as the exposures of granite and of Cretaceous sediments along Sauk River near Coldspring and Torah (Richmond), Stearns County, and the granite exposures on the upper Elk River about 8 miles northwest of Foley, Benton County.

Most of the outcrops occur in groups, but isolated, scattered outcrops are also abundant. The most northerly of the groups of outcrops is that south of Watab on the east side of Mississippi River. Three rocky knolls are found here between the tracks of the Northern Pacific Railway and the river. The knolls consist principally of a dark, fine-grained hornblende rock, probably a diorite. Locally between the knolls fine to medium-grained pink granite which appears to be intrusive in the diorite crops out. In the knoll farthest east near the railroad a quarry occurs in the pink granite, in which several phases are shown.

From Watab southward to Sauk Rapids exposures of diorite and pink and gray granite occur at frequent intervals. Most of them are found from 1 to 3 miles east of Mississippi River, but west of the river there are also scattered outcrops. About 1½ miles north of Sauk Rapids and 2 miles east of the river, are situated a number of quarries. Several different types of granite are taken from these, including medium coarse-grained pink hornblende granite and light to dark gray biotite and hornblende granite.

At Sauk Rapids a number of outcrops are found. On the east side of Mississippi River are exposures of dark gray hornblende granite, while on the west side below the bridge is an exposure of coarsely porphyritic rhyolite porphyry containing both feldspar and quartz phenocrysts in a gray, finely crystalline matrix.

The largest group of outcrops in the Saint Cloud region is situated about 2 miles southwest of Saint Cloud and occupies an area about 4 miles long north and south and about 3½ miles wide.[50] Pink and red granite and syenite exposures are abundant, being scattered at short intervals over the entire area, some of them being several acres in extent. The rock is described by Upham as principally syenite with predominating hornblende but also containing abundant mica.

Near Rockville, about 6 miles southwest of this group of outcrops, a number of massive[51] exposures of coarse-grained gray, biotite granite occur. Several of these exposures are forty or fifty rods in extent and rise forty or fifty feet above the surrounding level. They are found along Mill Creek south of the village and along Sauk River north of the village.

In Saint Augusta township about 4 miles east-southeast of Rockville,[52] an exposure of pink biotite granite is reported to occur near the center of section 19, T. 123N., R. 28W., while an outcrop of gray granite is reported in the northwestern corner of Linden township about 2½ miles south of Saint Augusta.[53]

The outcrops at Coldspring and Torah (Richmond) in Wakefield township are described as consisting mainly of coarse reddish syenite. The Coldspring outcrops occupy an area a quarter of a mile square. Several exposures of very hard, dark diorite are reported as occuring 2 miles east of Torah (Richmond). These are the southernmost outcrops of igneous rock in east central Minnesota.

In the northwestern part of Sherburne County several outcrops occur in Haven township[54] southeast of East Saint Cloud. A number of quarries are found near the State Reformatory about 2 miles from East Saint Cloud in a rock said to be fine-grained gray to red syenite. Exposures occur over a considerable area. About 2 miles south of the Reformatory in the west central part of the township is an outcrop of coarse whitish gray syenite[55] covering 4 or 5 acres and rising as a bare rounded knoll above the surrounding prairie.

---

[50] Upham, Warren, The geology of Stearns County: *Geol. and Nat. Hist. Survey of Minn., Geol. of Minn.*, vol. 2, 1882-1885, pp. 455-458.
Bowles, O., and Grout, F. F., Unpublished map.

[51] Upham, Warren, *op. cit.*, p. 454.

[52] Upham, W., *op. cit.*, p. 455.

[53] Bowles, O., and Grout, F. F., *op. cit.*

[54] Upham, Warren, The geology of Benton and Sherburne counties: *Geol. and Nat. Hist. Survey of Minn., Geol. of Minn.*, vol. 2, 1882-1885, pp. 426-444.

The outcrops northeast of Foley near the center of Benton County are reported by Upham to be only a few rods in extent and to consist of reddish syenite.

A group of granite outcrops of considerable extent is found northeast of the Saint Cloud region along the upper courses of the West Branch of Rum River and Saint Francis River in northeastern Benton and western Mille Lacs counties.[56] The outcrops on the West Branch of Rum River both in Benton and Mille Lacs counties are said to consist of remarkably uniform, coarse-grained, reddish syenite. They occur along the river through an extent of about 2 or 3 miles. Many different exposures are found, most of them small ledges occurring along the banks or in the channel of the stream. The westernmost group of exposures is a short distance above the mouth of Stony Brook in Benton County, while the easternmost exposures occur about 3 miles west of Milaca.

The outcrop near the headwaters of Saint Francis River is about four miles west of the westernmost outcrop on the West Branch of Rum River in the northern part of section 20, T. 38N., R. 28W. It is reported to be about 25 rods long by 15 rods wide and to consist of reddish syenite cut by an east and west trap dike. The dike is from a foot to a foot and a half wide and has fine-grained syenite on the north side and coarse-grained syenite on the south side.

NORTHERN MILLE LACS, KANABEC, SOUTHERN AITKIN, AND WESTERN PINE COUNTIES

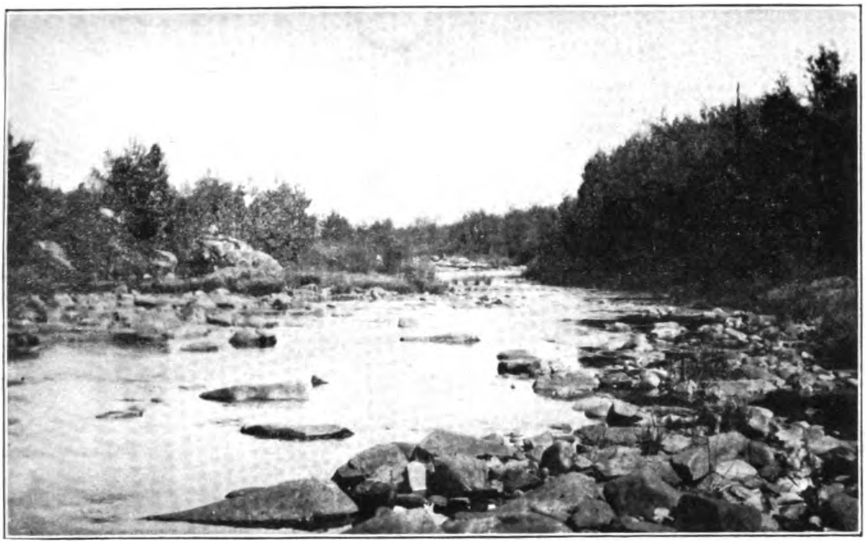
A number of outcrops of several different kinds of silicic igneous rock occur south and southwest of Onamia in the northern part of Mille Lacs County, some being on Rum River and some on Bradbury Brook, a tributary of Rum River.

The most northerly outcrop on Rum River is located about 5 miles south of Onamia near the ruins of an old logging dam. There is a bridge over the river at this point, and the exposures are on the east side of the river both north and south of the bridge. The principal rock is a light-colored, medium to coarse-grained granite, much of which has developed a gneissic structure and contorted, obscure banding. The banding is due in part to the arrangement of biotite in streaks and in part to a difference in size of grains of the different bands. The coarse granite is cut by several varieties of dark-colored dikes. One is a very dark, fine-grained

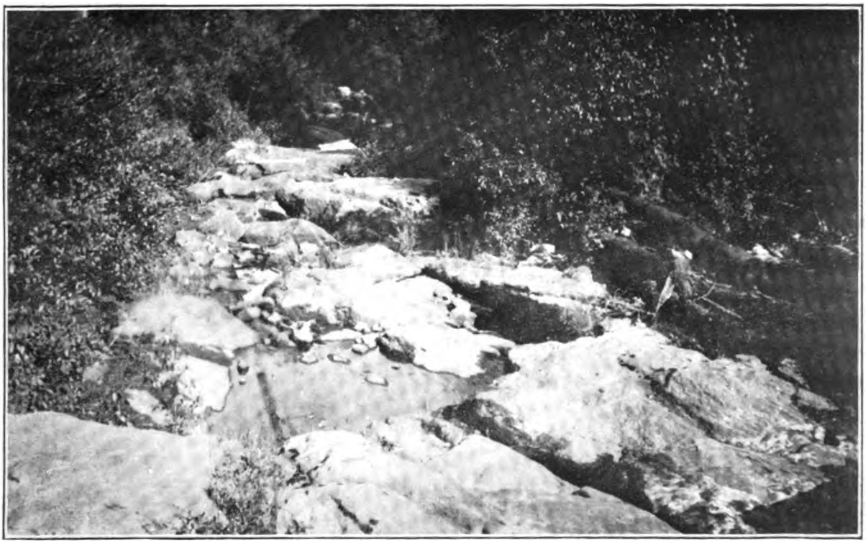
---

[55] Upham, W., *op. cit.*, p. 432.

[56] Upham, Warren, The geology of Mille Lacs and Kanabec counties: *op. cit.*, pp. 612-628.



A. GRANITE EXPOSURES ON RUM RIVER, SOUTH OF ONAMIA, MILLE LACS COUNTY



B. GRANITE EXPOSURES ALONG HAY CREEK, A BRANCH OF SNAKE RIVER, KANABEC COUNTY

UNIV. OF MICH.

biotite granite while the other is a dark, dense rock gray to greenish and fine-grained. The latter rock contains abundant pyrite.

The other outcrops on Rum River occur in section 7, T. 40N., R. 26W., and section 12, T. 40N., R. 27W. They form a series of three outcrops, two occurring in the NW¼ of NW¼ of section 7 and one in the NE¼ of NE¼ of section 12. All are found within a distance of about a half a mile along the stream.

The first of these outcrops, going down stream, consists of dark gray, fine-grained biotite granite, which has been squeezed so that the biotite has developed a parallel arrangement without segregation into bands thus giving the rock a schistose appearance. The rock, however, is quite massive.

The second outcrop consists of dense, fine-grained, mica schist. The rock has a dark greenish gray color and contains abundant flakes of muscovite, as well as biotite. It appears to be similar to the rock exposed in the outcrop last mentioned, but has suffered further deformation. Dikes of a dark-colored fine-grained feldspathic rock are found in it.

The third outcrop consists of light-colored medium coarse-grained granite consisting mainly of quartz and feldspar, but containing scattered biotite.

The exposures along Bradbury Brook consist mainly of light-colored gray or brownish granite with local gneissic phases. Three of the exposures occur on or near the South Fork of Bradbury Brook in section 25, T. 41N., R. 27W., and section 30, T. 41N., R. 26W., and another one occurs in section 13, T. 41N., R. 27W., a short distance east of the North Fork of Bradbury Brook.

The outcrop in section 13 is located on the quarter line about 1,000 feet west of the north-south township road between T. 41N., R. 27W., and T. 41N., R. 26W. The principal rock is a gray medium-grained granite with abundant biotite, which is more or less concentrated along parallel streaks due to deformation and recrystallization and gives the rock a gneissic appearance. It does not show distinct banding, however. The biotite granite is cut by several dikes of a very light-colored fine-grained to medium-grained quartz-feldspar rock (aplite) containing a little scattered biotite.

The northernmost of the exposures near the South Fork of Bradbury Brook occur along the township road between section 25, T. 41N., R. 27W., and section 30, T. 41N., R. 26W. about 1,400 feet south of the section corner. The rock here consists of medium coarse-grained light-colored granite with abundant quartz and feldspar and scattered biotite. Locally it shows a tendency to a gneissic texture, which is not very marked. This rock contains inclusions of a fine-grained, dark granite with abundant ferromagnesian minerals.

About 400 feet south of these exposures at the bridge over the South Fork of Bradbury Brook, a small outcrop of fine-grained, gneissoid granite occurs east of the road. The biotite shows in conspicuous parallel lines.

About 300 feet west of the outcrop at the bridge just mentioned, there is a dam on the South Fork of Bradbury Brook near which are found several exposures of medium-grained gray biotite granite. Some of the rock is light-colored and consists mainly of quartz and feldspar with scattered biotite, but in some of it the ferromagnesian minerals equal in amount or predominate over the quartz and feldspar and such phases are dark.

Upham[57] mentions the occurrence of several other rock exposures along Rum River and Bradbury Brook. Those on Rum River are said to be several miles above the mouth of Bradbury Brook and to consist of syenite, hornblende rock, gneiss, granite, and greenstone. Outcrops of this description have been looked for but have not been found by the writers. The outcrop on Bradbury Brook is reported to be on the South Fork 3 or 4 miles above its junction with the North Fork. As these exposures were not visited by Upham but were reported on the authority of others, it is probable that they have been confused with certain of the outcrops described above.

In the NW¼ of SE¼ of section 27, T. 42N., R. 26W., about 3 miles northeast of Onamia, exposures of granite and diorite are reported by Grout[58] to occur in the bottom of a cut along the Minneapolis, St. Paul, and Sault Ste. Marie Railroad. The outcrop rises from 2 to 3 feet above the grade and extends for 185 feet along the north side. Only a few exposures are found on the south side of the cut. The rock consists of alternate masses of fine-grained light gray biotite granite and dark gray medium coarse-grained diorite. The contacts are sharp and no change in the size of the grain is noticed on approaching them. Along one contact is a small pegmatitic band grading into the granite. A few small dark inclusions or blotches of ferromagnesian minerals are found in the granite.

About 5 miles southeast of Wahkon, Mille Lacs County, in section 3, T. 41N., R. 25W., a quarry has recently been opened in light gray granite. It is located in the northeast corner of the section in a bend of Knife River. The granite is of two kinds, one a medium coarse-grained rock, and the other finer grained. Both are very light colored and contain only a small percentage of ferromagnesian minerals. Their relation is such as to indicate that the fine-grained granite is intrusive into the coarse-grained granite. The fine-grained rock resembles very closely that found at Meyers quarry west of Pierz and is hard and fresh. Dikes and irregular masses of fine-grained aplite cut both varieties of granite.

---

[57] Upham, W., *op. cit.*, p. 617.

[58] Grout, F. F., Oral communication.

A number of granite outcrops are found in the region of Ann Lake, 4 to 7 miles northwest of Mora, Kanabec County. Near the boundary between sections 19 and 20, T. 40N., R. 24W., just north of the east and west road which runs along the south line of these sections, several exposures of medium-grained, pinkish gray biotite granite occur. They probably continue south of the road into sections 29 and 30. The principal exposure forms a small hummock overlooking a marsh a short distance north of the road. The rock here is a light pink biotite granite with abundant quartz and both white and pink feldspar.

Upham[59] reports the occurrence of ledges of gray fine-grained granite along Ann River in sections 30, 29, and 32 half a mile to a mile south of the locality mentioned above. He states that similar outcrops are reported as occurring also along Little Ann River north of Ann Lake in sections 26 and 14, T. 40 N., R. 25W.

Quarries in granite are located at Warman in the southeast corner of section 6 and the southwest corner of section 5, T. 41N., R. 23W. The granite is very light gray, medium-grained, with abundant quartz and white feldspar, and considerable amounts of scattered biotite. The rock is very even-grained and shows no abrupt changes in texture or mineral composition. Most of it is fresh and shows little or no alteration of the feldspars. At one of the quarries there are a few dikes of white feldspar-quartz pegmatite, containing scattered large thin biotite flakes.

Numerous outcrops of sedimentary and igneous rocks are found along Snake River in the northern part of Kanabec County. The southernmost of these exposures, consisting of several outcrops of flat-lying pink and red sandstone, are found in the northwestern part of section 23, T. 42N., R. 23W. The rock probably forms a part of the supposed upper Keweenawan sandstone which extends southwestward from the western end of Lake Superior. The outcrops are described later.

The next group of exposures to the north up Snake River is found beyond the big bend in the river in sections 15 and 16 of the same township. The river at this point flows eastward and the locality, which is known as Lower Falls, is a short distance west of the new iron bridge over the river. The exposures consist of gray and pink biotite granite with large included masses of biotite schist.

---

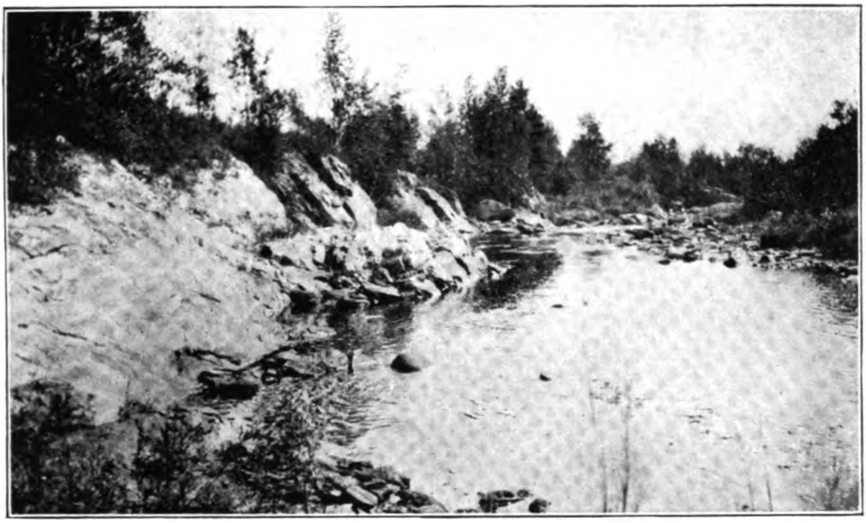
[59] Upham, Warren, The geology of Mille Lacs and Kanabec counties: *Geol. and Nat. Hist. Survey of Minn., Geol. of Minn.*, vol. 2, 1882-1885, pp. 617 and 618.

Up the river beyond this group of exposures there is a number of scattered granite outcrops as far as the mouth of Hay Creek, while north and northwest of the mouth of Hay Creek exposures again increase in abundance and cover an area of considerable size in sections 16 and 9. In this area many large outcrops occur both westward along Hay Creek and northward along Snake River. They extend up Hay Creek for nearly a mile and up Snake River from the mouth of Hay Creek about a third of a mile to a place known as Upper Falls where a reef of rocks runs across the stream. The rocks in this area are mostly gray and pink biotite granite, but locally there are pegmatitic facies and also included bands of biotite schist. There are also several fine-grained basic dikes.

Above Upper Falls only a few scattered outcrops are found along the river as far as the mouth of Cowan Brook. About 800 feet above the mouth of Cowan Brook, however, near the northern boundary of section 9, a number of small exposures of schist and granite occur on both sides of Snake River, while about a third of a mile farther up an important group of exposures is found along Snake River and east in the area between Snake River and Cowan Brook. These outcrops are in the southeastern part of section 4. They consist mostly of light-colored granite with local gneiss and pegmatite. The entire area occupied by the outcrops of Lower Falls, Hay Creek, Upper Falls, and Cowan Brook is about 2 miles wide east and west and 2½ miles long north and south.

The principal exposures at Lower Falls extend along the river for a distance of about 3,000 feet, but small scattered outcrops continue both up and down the river. By far the most important rock is gray and pink biotite granite. This rock is medium-grained and hard and fresh, containing abundant quartz. There seems to be no distinct difference in age between the gray and the pink types, the former grading into the latter with increasing pink feldspar. As far as can be determined from these exposures, there is no sharp line between them. The amount of ferromagnesian minerals in the granite is usually small, giving the rock a light color.

The schist, which occurs as large masses surrounded by granite, is principally a fine-grained, quartzose biotite schist, but some of it is coarsely crystalline. Locally muscovite occurs with the biotite and along certain streaks and bands much hornblende is developed. Garnet also is commonly disseminated through the rock, while certain hard quartzitic lenses have an interesting development of molybdenite around the borders. The larger of the schist masses have a fairly uniform strike east and west and dip to the south at angles varying between 50° and 70°. They are cut by dikes of pink granite and also locally by pink pegmatite



A. GRANITE AND MICA SCHIST OUTCROPS AT LOWER FALLS ON SNAKE RIVER, KANABEC COUNTY

B. GRANITE EXPOSURES AT UPPER FALLS ON SNAKE RIVER, KANABEC COUNTY

UNIV. OF MICH.

dikes consisting of quartz and pink feldspar with abundant muscovite. The association shows that the granite is intrusive into the schist, the masses of the latter being fragments caught in the granite. If the schist is of upper Huronian age, as is generally supposed, then the granite is post-upper Huronian and may be equivalent to certain other Keweenawan granitic rocks of the Lake Superior region. Because of the isolated situation of these rocks, however, correlation is difficult, and the age relationships are therefore uncertain.

The rock exposures along Hay Creek and along Snake River near Upper Falls, are in general similar to those at Lower Falls in that they consist largely of medium-grained gray and pink granite. There is more pegmatitic rock, however, in these exposures and locally also the granite is quite fine-grained in texture. Pegmatite is especially abundant at Upper Falls and along both sides of the river below Upper Falls. In places, large masses of very coarsely crystalline material occur, consisting of pink feldspar, quartz, and muscovite, with locally some biotite. Usually the muscovite is in large flakes, but some of the pegmatite has suffered deformation and the muscovite is recrystallized into small flakes having a fan-shaped, foliated structure around fragments of quartz and feldspar. The granite also in a few places has suffered deformation and has developed a gneissoid texture. In one or two places it has even become coarsely schistose. Dikes of very fine-grained, dark greenish gray subsilicic igneous rock occur in the river at Upper Falls and at the dam on Hay Creek about a mile above its mouth. The one at Upper Falls shows diabasic texture while the one on Hay Creek appears to be a diorite. Masses of fine-grained quartzose biotite schist similar to that at Lower Falls occur locally in the Hay Creek and Upper Falls outcrops, but their development is not as abundant as in the former locality.

The exposures along Snake River between Upper Falls and the mouth of Cowan Brook as well as those a short distance above the mouth of Cowan Brook consist of light-colored pink and gray biotite granite with a considerable quantity of fine-grained biotite schist. Those above the mouth of Cowan Brook contain a large pegmatite dike.

The outcrops situated in the area between Snake River and Cowan Brook, about a third of a mile above the mouth of the latter, consist of light-colored biotite granite. Both the pink and gray types occur, most of the rock being very low in ferromagnesian minerals. Muscovite in small flakes is abundantly disseminated through it locally. In a few places there are gneissoid phases, showing distinct banding.

In the southwestern part of section 21, T. 43N., R. 23W., Aitkin County, about 3 miles north of the Cowan Brook exposures, there are several outcrops of schistose and banded gneiss along Snake River. The locality is known as Malloy (or Malloid) Dam. The rock seems to be a deformed and recrystallized granite. It varies from pink or white to dark gray in color. Most of it is finely crystalline biotite gneiss, biotite, quartz, and feldspar being arranged along fine laminae. The laminae of biotite are very thin, while those of quartz and feldspar are thicker and more irregular. There may be 20 or 30 thin laminae of biotite to the inch separated by thicker laminae of quartz and feldspar. Usually the successive laminae are closely similar, giving the rock a homogeneous and schistose appearance. Locally, however, there is a distinct banding of light and dark layers and the rock becomes a banded gneiss. The dip of the schistosity and banding varies from 65° to 80° north, the strike being nearly east and west. At one point a dike of pink granite cuts across the gneiss. It shows no deformation whatever. This dike rock is identical in appearance with the pink granite occurring along the Snake River in Kanabec County which contains included masses of schist. It appears that the gneiss and schist are older formations which have been rendered schistose previous to the intrusion of the granite. The granite predominates to the south in Kanabec County, while gneiss and schist predominate to the north in Aitkin, Pine, and Carlton counties.

Southwest of McGrath, a station on the Minneapolis, St. Paul, and Sault Ste. Marie Railroad east of Mille Lacs Lake, many outcrops of fairly coarse pink augen-gneiss occur on both sides of the east-west road running between section 1 and section 12, and section 2 and section 11, T. 43N., R. 24W. The outcrops extend for a mile along the road and all seem to be composed of the same kind of rock. The rock at one time was apparently a fairly coarse-grained granite with numerous prominent crystals of feldspar and some of quartz. Deformation occurred, and during this process the biotite and some of the quartz and feldspar were crushed and recrystallized. Other quartz and feldspar crystals, however, resisted deformation and remained as lentils or buttons around which the crushed material recrystallized, giving the rock a wavy, foliated texture. The buttons of quartz and feldspar are coarse-grained, many consisting of a single crystal, while the crushed and recrystallized material is fine-grained. The foliated structure is fairly regular. It strikes about N. 70° W. and the dip is vertical or steeply inclined to the south.

Augen-gneiss similar to that occurring near McGrath, as well as banded and schistose gneiss, are found cropping out at several places west and south of Denham, a station on the Minneapolis, St. Paul, and Sault Ste. Marie Railroad in Pine County, about 20 miles northeast of McGrath. The distribution of the outcrops indicates that the southern part of Aitkin County and the northwestern part of Pine County are largely underlain by gneiss, which is bounded on the south by granite and on the north by metamorphosed sediments such as schist and slate.

The most westerly of these exposures are in the southwestern part of section 35, T. 45N., R. 22W., Aitkin County, along the north and south road south of Arthyde. Two exposures occur in the road. One of them consists of pink augen-gneiss very similar to that at McGrath, while the other consists of finely laminated, dark-colored schistose gneiss, with thin lentils of crushed pink feldspar and quartz. The dark color is due to the abundance of biotite which occurs in fine laminae. The rock is probably a more metamorphosed phase of the augen-gneiss.

About 2 miles west of Denham a rock cut along the railroad in section 21 T. 45N., R. 21W., Pine County, shows dark-colored, schistose gneiss. The degree of metamorphism varies in different parts so that in places the rock is a perfect schist, finely laminated, consisting largely of biotite, while elsewhere it is more massive and contains abundant feldspar and quartz. This variation produces a rough banding more or less parallel to the foliation. The foliation or schistosity strikes roughly east and west, and dips to the north at angles varying between 70° and 80°. The rock is similar to that in one of the outcrops south of Arthyde but the "augen" structure is less marked.

About 1¼ miles south of the locality just described, on the north and south road between sections 33 and 34, T. 45N., R. 21W., pink augen-gneiss similar to that at McGrath, outcrops at several places while a mile further south between sections 3 and 4, T. 44N., R. 21W., other exposures of the same type of rock are found. In the latter locality the gneiss shows a considerable amount of muscovite.

Several exposures of gneiss with associated hornblende schist are located in the western part of the township of Bremen, T. 44N., R. 21W. The most northerly of these are found along the northern headwaters of Pine River in the northeastern corner of section 17 and adjacent parts of sections 16, 8, and 9. An outcrop on the west bank of the stream near the east quarter post of section 17 consists of pink gneiss, very coarse and containing muscovite and biotite along foliation planes. The foliation strikes approximately east and west and dips about 50° S. Along the north and south section road, near the northeast corner of section 17, and extending into the adjoining sections to the east and north, are several exposures of dark reddish gneiss with closely spaced foliation planes and of very dark, almost black, finely laminated hornblende schist. The gneiss contains abundant mica along foliation planes, the close spacing of which indicates intense deformation and metamorphism. The hornblende schist shows continuous fine laminae of hornblende alternating with laminae of quartz and feldspar. The hornblende is by far the most abundant mineral in the schist and produces a schistosity parallel to the lamination. The hornblende schist appears to be a phase of the gneiss but the relation of the two rocks could not be determined. The general dip of the foliation in these outcrops is 35° S.

The other outcrops in the township of Bremen are located along a branch of Pine River on both sides of the north and south section line between sections 19 and 20. The principal exposures are found on both the north and south banks of the stream south of the east and west quarter line. They consist of pink, fresh looking, distinctly foliated gneiss, some of which shows a somewhat indistinct "augen" texture and some the more regular interbanding of feldspar and quartz with mica. The former as a rule is more coarsely crystalline than the latter. The ferromagnesian minerals occur along foliation planes, both biotite and hornblende being present. The foliation planes as a rule are thin, irregular, and discontinuous, but locally they widen forming lense-like bunches of dark minerals. The general dip of the foliation is to the south, varying between 40° and 80°.

A group of small rock exposures occurs a short distance south of the stream near the south line of section 20 not far from the southwest corner. These are of gneiss. Hornblende and biotite schists also occur here. The gneiss varies in texture from very coarsely crystalline to medium finely crystalline and in color from gray to pink. Nearly all of it is distinctly but irregularly banded. In some places the segregation of light and dark minerals is very perfect, so that white or pink bands of intermixed feldspar and quartz ranging up to half an inch thick are interlayered with darker bands of feldspar, quartz, and ferromagnesian minerals. The hornblende and biotite schists are dark-colored, often black or greenish black and generally are finely and regularly laminated due to interlayering of fine-grained feldspar, quartz, and ferromagnesian minerals, mainly hornblende. The ferromagnesian minerals are much more abundant than the light-colored minerals, but locally layers up to a fourth of an inch in thickness, consisting almost entirely of feldspar and quartz, occur interlaminated with the dark minerals. Some of the schist shows irregular undulatory lamination and marked schistosity, usually being more coarsely crystalline and appearing to have suffered greater metamorphism than the more regularly banded schist. Most of the schist is fairly pure hornblende schist, but local phases show a considerable admixture of biotite. Interesting phases, gradational in texture as well as in mineral composition, occur between the gneiss and the schists. In some of these the light and dark-colored minerals are almost equally abundant and light-colored layers are interbanded with dark-colored layers. Some of them show gneissoid, and some show schistose textures. It seems quite clear, therefore, that the gneiss and schists belong to the same rock mass, the one representing the more silicic and the other the less silicic portions of it. The latter appear to have yielded more readily to deformational forces. The dip of the foliation and schistosity is to the south at angles varying between 40° and 70°.

A number of exposures of augen-gneiss of considerable size occur in the southeastern part of the NE¼ of section 36, T. 45N., R. 21W. The outcrops are about 1½ miles south of Denham and a short distance south of a group of exposures of interesting metamorphosed sedimentary rocks found in the southeastern portion of section 25 which is described later. An isolated exposure of dark greenish black hornblende-biotite schist is found north of the gneiss outcrops about half-way between them and the outcrops of metamorphosed sediments.

Most of the rock composing the gneiss exposures is a gray to pink augen-gneiss with distinct undulatory foliation. The large crystals forming the augen are of pink feldspar and present all stages of crushing, the foliation in the ground-mass curving around them. The ground-mass is mainly quartz, feldspar, biotite, and muscovite, all finely crystalline. In some phases muscovite is present almost to the exclusion of biotite. A small mass of biotite schist is found in one of the outcrops. It contains considerable feldspar and is probably a sheared basic inclusion.

The hornblende-biotite schist found north of the gneiss outcrops is similar to that occurring in Bremen township. It shows a distinct, irregular schistosity, but the lamination is not very marked. Hornblende predominates, while biotite and quartz and feldspar are present in minor amounts. This is the easternmost outcrop of gneiss known in central Minnesota.

OUTCROPS OF SUBSILICIC IGNEOUS ROCKS

TODD COUNTY

Outcrops of several kinds of coarse-grained, subsilicic igneous rocks occur in the northern part of Todd County. They are situated on Long Prairie River at the mouth of Fishtrap Creek and along Fishtrap Creek for about 1,300 feet above its mouth. The principal exposures consist of coarse-grained, dark greenish or brownish black gabbro. The largest outcrop of this rock is at the mouth of Fishtrap Creek, but numerous small outcrops extend southward up the creek, occurring on both banks of the stream. The last exposure up stream is an isolated outcrop found on the west bank a short distance above the first road bridge. This bridge is 1,000 feet from the mouth of the creek.

Besides the gabbro there are a few outcrops of anorthosite. One of these is on the east side of Fishtrap Creek near its mouth, and another is at the road bridge over Fishtrap Creek mentioned above.

The gabbro has suffered considerable alteration so that it consists principally of feldspar and secondary hornblende. The feldspar is more or less altered to saussurite and locally to muscovite and quartz. Apatite and magnetite are abundant in the rock and biotite also is present. The hornblende is secondary after diallage, traces of which are found in a few of the outcrops, notably in the one above the bridge. The rock in its original fresh state, therefore, consisted mainly of feldspar and diallage with biotite, apatite, and magnetite as accessory constituents. The anorthosite is composed almost entirely of feldspar, some of which has been partly altered to saussurite and some to muscovite and quartz.

A short distance east of the station of Philbrook, about 2,000 feet up Fishtrap Creek from the southernmost of the exposures just mentioned, there are a few small outcrops of coarse-grained greenish rock very much altered. Most of the rock is composed of saussuritized feldspar, green hornblende, and epidote, but some phases of it consist almost entirely of altered feldspar. Magnetite is abundant. The rock, although somewhat lighter in color, is similar in texture to the gabbro and anorthosite occurring near the mouth of Fishtrap Creek and it seems probable that it represents a further alteration phase of these rocks.

MORRISON, BENTON, AND STEARNS COUNTIES

Several exposures of subsilicic and intermediate igneous rock are found in the vicinity of Little Falls, Morrison County. One of these is at Williams' quarry in the northeast quarter of section 13, T. 129N., R. 30W., about a mile northeast of Little Falls. The rock varies greatly in texture at different points in the quarry. Some of it is dense and fine-grained and has a uniform dark gray color, while other phases are coarser grained and have a speckled appearance due to intermixed light and dark-colored minerals. The latter vary considerably in size of grain, as well as in color. In some, feldspars predominate; in others, ferromagnesian minerals. The various rocks have a fairly uniform mineral composition, except that the coarser grained varieties have suffered greater alteration.

The fine-grained type consists of feldspar and pyroxene, the former predominating. It is fairly even-grained, but occasional larger crystals of pyroxene occur. Fine particles of magnetite are scattered throughout the rock. Much of the feldspar shows partial alteration to granular kaolin, while the pyroxene shows practically no alteration. The coarser grained type consists mainly of feldspar and hornblende, the latter being secondary after pyroxene. Locally much of the hornblende shows irregular cores of pyroxene, the hornblende forming a border of varying thickness. Most of the hornblende shows pleochroism from bluish green to light yellowish green. Some of it is greenish brown. Both varieties of hornblende show pyroxene cores in places, but elsewhere the pyroxene has entirely disappeared. The feldspar is slightly altered to kaolin. A small amount of biotite (or phlogopite) is quite generally distributed through both types of rock, while locally large, very thin, flakes of phlogopite occur, giving the rock a bronzy appearance. In the phases of the rock rich in phlogopite, the pyroxene is quite fresh, and much brown hornblende occurs in irregular masses which has the appearance of being original. It is quite probable that a considerable amount of both brown and green hornblende is original. Locally the feldspar predominates over the ferromagnesian minerals to such an extent as to give the rock a very light color. Specks and irregular grains of magnetite are numerous, especially in association with pyroxene, while grains of quartz occur rarely. In general the rock has the composition of a diorite.

The diorite at Williams' quarry and the syenite occurring on the east bank of Mississippi River at Little Falls, are within a region in which slate and schist of sedimentary origin predominate. As the metamorphosed sediments have a fairly definite and regular structure throughout, it would seem that the igneous rocks are probably intrusive into them, although contacts between them have not been found.

An outcrop of hard, dark rock occurs on the west bank of Mississippi River about three quarters of a mile below the bridge of the Minneapolis, St. Paul, and Sault Ste. Marie Railroad, in section 32, T. 128N., R. 29W. It forms rapids in the river, known as Blanchard's Rapids, and outcrops of it are found on the east bank also. The rock is medium coarse grained and contains abundant pyroxene and calcic feldspar with locally phlogopite. It resembles gabbro in composition. Only a short distance above these outcrops, along the river bank, are exposures of staurolitic and garnetiferous biotite schist which are apparently the southernmost outcrops of these rocks on Mississippi River. The relation of the schist to the igneous rock could not be definitely determined. Judging from the fact, however, that the cleavage of the schist strikes in the direction of the gabbro it would seem that the latter is intrusive, as is the case with the other subsilicic or dark igneous rocks in the vicinity of Little Falls.

The occurrence of a dark-colored hornblende rock on Skunk River near the locality known as Rucker, in the northwestern part of Morrison County, has already been mentioned. The rock is dark grayish in color and contains abundant specks of granular hornblende. It is probably a hornblende syenite, but may approach a diorite in composition.

The outcrops of various rocks of intermediate composition in Benton and Stearns counties have been mentioned in connection with the descriptions of the outcrops of silicic igneous rocks of these counties, while the occurrence of gabbro also has been noted. Diorite is mentioned as occurring in the vicinity of Watab in the western part of Benton County, and near Torah (Richmond) and Cold Spring in the southern part of Stearns County. Only one group of gabbro exposures is known in this region, being located in the northeastern corner of T. 125N., R. 29W., and adjacent parts of T. 125N., R. 28W., in Stearns County. It occupies portions of several contiguous sections.[60]

AITKIN, CARLTON, AND PINE COUNTIES

Among the most important rock outcrops in central Minnesota with reference to the geology of the Cuyuna district, are those of quartzite, diorite, and diabase on the shores of Dam Lake and Long Lake in central Aitkin County, about 3 to 6 miles south of Kimberly. There are two quartzite outcrops, both located on the northwest shore of Dam Lake, one in section 34 and the other in section 35, T. 47N., R. 25W. They are described in connection with the metamorphic rocks. The diabase and diorite outcrops are southwest of the quartzite outcrops occurring on both the east and west sides of Long Lake in sections 9 and 10, T. 46N., R. 25W.

The outcrops in section 9 are by far the most extensive, occupying an area of 8 or 10 acres west of the southwestern end of Long Lake. The rock is dark green in color and is in general fine-grained. Medium coarse-grained phases, however, occur as well. All show a distinct diabasic texture. The rock appears to be less silicic in character and darker in color than that composing the outcrops east of Long Lake. It consists of pyroxene, basic feldspar, and green hornblende. Scattered quartz grains occur frequently and magnetite is disseminated through it. The rock is massive and fresh-looking.

On the east side of the lake two small groups of outcrops occur; one along the top of an elevation overlooking the northeastern part of the lake, and the other one a short distance from the mouth of a small brook which empties into the southeastern part of the lake. Both occur in section 10.

The group of outcrops at the northeastern end of the lake consists of three or four exposures, all of them quite small. The rock is medium to dark gray in color and massive, resembling diorite in appearance. It is medium to fine grained and consists of feldspar and pyroxene with some green hornblende and mica and scattered pyrite specks.

The outcrops on the southeastern side of the lake are on the banks of a small brook about 200 feet from its mouth. Two types of rock occur here. One is a gray massive rock similar to that occurring at the northeastern end of the lake, while the other is a lighter gray, schistose, micaceous rock which appears to be an alteration product of the massive rock. The schistose rock is found along irregular zones in the massive rock, all gradations occurring along the contacts. The rock is finely and distinctly laminated, white laminae, probably of crushed feldspar, being interlayered with gray laminae containing mica and other ferromagnesian minerals. The most conspicuous mineral in it is white mica which occurs in tiny flakes parallel to the lamination and produces the schistosity.

---

[60] Bowles, O., and Grout, F. F., Unpublished map.

The igneous rocks at Long Lake are designated by Van Hise and Leith[61] as Keweenawan, and are believed to be intrusive into the upper Huronian metamorphosed rocks of this region. Winchell,[62] on the other hand, believed that they are equivalent to the Keewatin greenstone of northern Minnesota, and that they formed the basement on which the later sediments were deposited. The former draw their conclusions from the fact that numerous dikes of subsilic igneous rock similar to those occurring at Long Lake are found in Carlton County, and elsewhere cutting schists and slates of upper Huronian age, while the latter notes the similarity between these rocks and the greenstone of the Vermilion district and believes that the quartzite at Dam Lake overlies them.

There are a number of localities in the Cuyuna iron-ore district where subsilicic and intermediate rocks have been shown by drilling to be interlayered with the series of metamorphosed sedimentary rocks, and seem to have been deformed with them. They are evidently not basement rocks on which the metamorphosed series was deposited, nor are they later intrusives in the series. Such rocks are evidently of approximately the same age as the metamorphosed rocks, and bear a relation to them similar to that which the Hemlock volcanic rocks bear to the middle Huronian metamorphosed sediments of the Crystal Falls district of Michigan.

Subsilicic rocks of this character that have suffered considerable deformation and alteration are found outcropping at a number of localities in Carlton and Aitkin counties besides the Long Lake area already mentioned. Some of these occurrences simply exhibit schistosity while in others considerable metamorphism and recrystallization of the minerals have taken place. The rock differs distinctly from that which occurs as dikes and intrusive masses in the slate occurring along St. Louis River or in the schist and slate of the Cuyuna district. While it is not impossible that post-Keweenawan deformation may have produced changes in these rocks, it seems more logical, in view of the fact that igneous rocks are known to be associated with the schists of the Cuyuna district, to class the more altered types of subsilicic and intermediate igneous rocks with this older group.

---

[61] Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: *U. S. Geol. Survey Mon.* 52, Pl. 14, 1911.

[62] Winchell, N. H., The Cuyuna iron range: *Econ. Geology*, vol. 2, p. 568, 1907.

Carlton County contains outcrops of subsilicic igneous rocks both of the older and the later types in many places.

In the NW¼ of SW¼ of section 19, T. 47N., R. 21W., a short distance north and west of Dead Moose River, and just east of the boundary line between Carlton and Aitkin counties, are several low exposures of subsilicic igneous rock. At the western end the group of outcrops is covered for the most part by large boulders. In the central and eastern parts, however, the outcrops rise a few feet above the surrounding area and slope gradually toward the river. The exposures occupy an area about 1,500 feet long east and west, by 400 feet wide north and south. The rock along the north and south sides of the group of outcrops is medium coarse-grained and of a dull grayish green color. It is made up largely of feldspar and hornblende with probably some pyroxene and small scattered crystals of magnetite and pyrite. It may be a diorite or an altered gabbro. In the center of the group of outcrops between the two areas of medium coarse-grained rock, is a dull, dark gray rock with fine-grained texture. This rock has suffered considerable alteration so that it is difficult to tell its nature without thin sections. It contains considerable carbonate, and from field relations it appears that the rock is probably derived from the alteration of the original diorite or gabbro. In the central part of the area of this rock is a light gray, crystalline, carbonate rock made up largely of carbonate and quartz with scattered pyrite crystals. Under surface conditions, the carbonate in it alters to a hydrous oxide of iron, suggesting that at least part of it is iron carbonate. Quartz veins and pegmatite dikes, vertical or dipping steeply to the south and trending about east and west, cut the other rocks. At the contact of the medium coarse hornblende-feldspar rock and the fine-grained altered rock, some shearing has taken place, giving the rock a slightly banded structure. The bands strike N. 56° W., and dip steeply to the south.

In the SW¼ of SE¼ of section 20, T. 46N., R. 21W., on the land of L. Pevon, an outcrop of fine-grained diabase occurs south and east of the farm-house. The main outcrop trends a little north of east for a distance of about 300 feet, while a smaller exposure which is badly decomposed by weathering, occurs about 100 feet farther east. The rock is a dark gray or green, massive, fine-grained, altered diabase. Small grains of pyrite occur abundantly throughout the mass. Near the center of the outcrop a belt of schistose rocks from 5 to 8 feet wide extends from north to south. Running parallel with the schistosity are narrow white bands of calcite. From the field relations, it appears that shearing has taken place between the two masses of diabase, and this schist is a shear zone product. The strike of the schistosity is about N. 40° E. and the dip is 67° southeast. At the west end of the outcrop is a quartz vein six inches wide striking east and west and dipping steeply to the south. On both sides of this vein for a few inches from the contact the rock also is schistose. All gradations can be found in the outcrop from the schistose phases to the massive diabasic phases. In this respect it resembles somewhat the exposure occurring on the southeast side of Long Lake in Aitkin County. The occurrence of the schist indicates that the rock has suffered considerable metamorphism after it was intruded.

Several outcrops of dark igneous rock occur on both sides of the north-south road between sections 14 and 15, T. 46N., R. 21W. The typical rock is a greenish black, very fine-grained diabase, but schistose phases occur intermixed with the massive rock. The southernmost exposure lies about 60 feet west of the road and about 750 feet north of the southeast corner of section 15. It consists mainly of light greenish gray hornblende schist, impregnated with specks of pyrite and containing small scattered crystals of feldspar and calcite. The strike of the schistosity is N. 70° E., and the dip is about 50° to the south. The next outcrop to the north in this group is 50 feet south of the quarter line. The larger part of the exposure lies in section 15; but it crosses the road and extends a few feet into section 14. It is a dark grayish green, or greenish black, dense, fine-grained diabase, made up principally of fine lath-shaped crystals of feldspar with associated hornblende, pyroxene, and scattered crystals of pyrite and magnetite. The central part of the outcrop is slightly sheared, developing an incipient schistosity. The original texture is still retained, but it has undergone some alteration along the shear planes where an abundance of mica has developed. A quartz vein a foot and a half wide with a vertical dip, and trending almost due north and south, cuts the west end of the outcrop, while smaller stringers of quartz and pegmatitic material are of frequent occurrence. Most of them fill north and south joints, but a few run east and west. The remaining outcrop in the group consists of two small exposures of rock similar to that described above, located about 200 feet north of this on the west side of the road, and a larger one situated about 780 feet north of the quarter line on the east side of the road. The latter outcrop occurs at the roadside and extends eastward for about 300 feet. The rock differs from that described above in being more schistose. The schistosity strikes about N. 65° E., and dips about 50° to the south. Some phases of this rock consist of well developed schist. Scattered through parts of the rock are small white spots made up principally of white feldspar, giving the rock a mottled appearance. These are elongated parallel to the schistosity. Along the shearing planes, some of which show slickensides, sericite is abundantly developed. This rock, as far as its general appearance is concerned, is similar to that in the NE¼ of NE¼ of section 4, T. 46N., R. 21W., described below.

Two small outcrops of dark igneous rock occur in the NE¼ of NE¼ of section 4, T. 46N., R. 21W., on the land of William Michalski. The outcrops lie in the cleared field between the road and the house. The rock is medium-grained, light grayish green diabase, considerably altered. In the easternmost outcrop the rock is massive, while in the outcrop to the west the rock has suffered considerable dynamic metamorphism producing a schistose structure. The schistosity strikes about N. 65° E. and dips about 45° to the south. The rock contains long, slender plagioclase crystals imbedded in a light green to gray, fine-grained ground-mass. Occurring abundantly throughout the rock are larger crystals of white feldspar largely altered to calcite, giving the rock a porphyritic appearance. Calcite occurs not only as an alteration of the large crystals, but also abundantly in the fine-grained matrix.

In section 28, T. 47N., R. 20W., about 600 feet due east of the west quarter post, an outcrop of highly altered diabase occurs on the face of an escarpment which rises about 25 feet above the bottom of the valley of Kettle River. The escarpment runs about N. 30° E. and for about 175 feet the rock is exposed along it. The diabase is massive, dull, grayish green and very fine-grained. Calcite occurs as an alteration of the feldspar, but the original diabasic texture is still retained. Besides chlorite and hornblende, which are probably mainly alteration products, there are small grains and aggregates of magnetite and pyrite. Quartz veins are abundant and thin films of quartz occur along the joint planes.

On the opposite side of Kettle River from the outcrops described above, about 100 feet south of the northeast corner of NW¼ of the SW¼, section 28, T. 47N., R. 20W., two small exposures of rock lie at the water's edge on the bank of the river. About 300 feet southwestward a low escarpment rises 20 feet above the river. Near the edge of the latter, also, rock is exposed for a distance of about 125 feet. The rock composing these exposures is a dark grayish green, finely crystalline, igneous rock, much of which shows a fine ophitic texture. In places the rock is dense, while elsewhere it shows a well-developed schistosity. The strike of the schistosity is about N. 45° E. and the dip is 70° to the southeast. The outcrops in section 28 have the appearance of being composed of fine-grained diabase which has locally suffered considerable dynamic metamorphism. The rock is very similar to other subsilicic igneous rocks exposed in the southwestern part of Carlton County which are judged to be flows or intrusive sheets interlayered with the metamorphosed sedimentary rocks of the region. This has already been discussed in connection with the description of similar rocks found at Long Lake in Aitkin County.

Another outcrop of schistose dark igneous rock occurs about 650 feet east of the northwest corner of the NW¼ of the NE¼, section 2, T. 46N., R. 20W., and continues southwestward across the forty-acre tract toward the north-south quarter line. It lies in a low, flat, glaciated ridge, partly covered by a thin mantle of soil. The rock is dark greenish gray, dense and fine-grained, and has well-developed cleavage. It is comparatively fresh and appears to have a fine diabasic texture. It is similar to that occurring in the NE¼ of SE¼ of section 15, T. 46N., R. 21W. Several sets of joints cut the rock into large polygonal blocks. The cleavage strikes about N. 45° E. and dips 17° to the southeast.

Near the center of section 5, T. 47N., R. 18W., on the south side of Park Lake River, two outcrops of dark igneous rock, occupying an area about 180 feet long and 120 feet wide, rise 10 to 15 feet above the meadow. They form two small knolls elongated in an east-west direction, one being north of the other. The rock is dark gray and medium-grained, resembling diorite. The principal minerals are feldspar, hornblende, magnetite, and pyrite. The edges of the larger feldspar crystals have been somewhat altered. Large cubes of pyrite are scattered abundantly through the rock. About a quarter of a mile north is an outcrop of similar rock which, however, is somewhat schistose and in places is mottled due to the presence of white grains of feldspar and calcite.

Small dikes or sheets of subsilicic igneous rocks occur quite commonly in the belt of slate extending along St. Louis River in northern Carlton County and thence southwestward through central and southern Carlton County, and outcrops of them have been noted in many places. They are mentioned in connection with the descriptions of these rocks. One of the larger ones of these is an outcrop of much altered diabase which lies in the bed of West Branch of Moose Horn River in the SW¼ of NW¼, section 15, T. 47N., R. 19W. It occurs intrusive into graphitic slate. Dikes of fresh gabbro and diabase cut the slates and phyllites in the valley of St. Louis River, being especially abundant near the Thomson dam and elsewhere between Carlton and Cloquet.

Dikes of dark igneous rocks have also been mentioned as occurring in various silicic igneous rocks of east central Minnesota, already described, such as those found along Snake River and Hay Creek.

A large number of outcrops of subsilicic volcanic rocks occurs at various points in eastern and southeastern Pine County. They form a part of the area of Keweenawan igneous rocks which extends southwestward from Douglas County, Wisconsin, into eastern Minnesota, forming the so-called "south escarpment." The rocks are practically all of eruptive origin, consisting of massive diabase with texture varying from medium coarse to extremely fine and of various types of amygdaloids. Locally tuffaceous layers occur, but they are not abundant. These rocks have been mentioned in the section on the general geology of east central Minnesota. They bear no direct relation to the rocks of the Cuyuna iron-ore district, and need not be discussed further here. They have been mapped and described in detail by Grout.[68]

OUTCROPS OF SLATE, SCHIST, AND OTHER METAMORPHIC ROCKS

MORRISON AND BENTON COUNTIES

The westernmost of the outcrops of metamorphic rocks in central Minnesota are chloritic schists found in the vicinity of Randall. They cover an area nearly half a mile long north and south, and about 500 feet wide. The north end of this area of outcrops is at the railway station, the rock being exposed in a cut nearly opposite the station. The outcrops are not continuous but occur at frequent intervals, southwest of the railroad and of the north branch of Little Elk River.

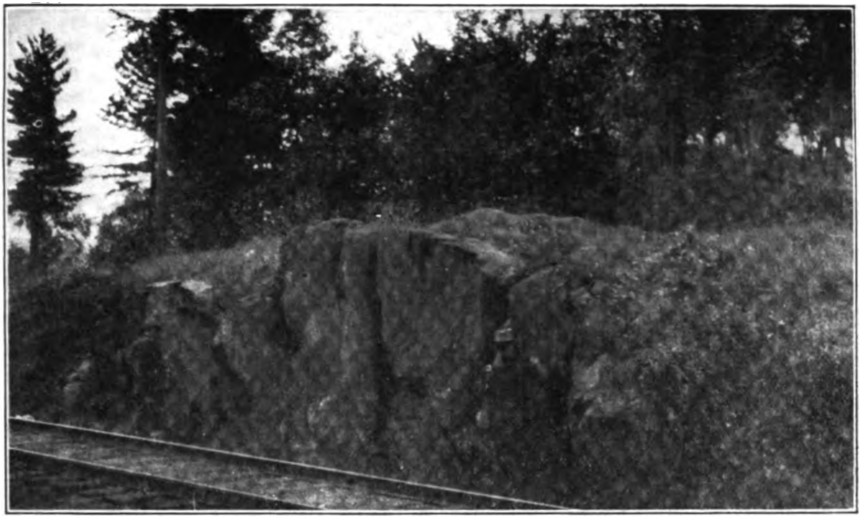
The chloritic schist is dark green and is essentially similar in all the exposures. It is commonly fine-grained and shows a marked but uneven cleavage which has a general direction of N. 40° E. and has dips varying from vertical to 70° northwest. No bedding is distinguishable. (Plate VI.)

The rock is essentially a fine-grained mixture of chlorite and feldspar with some quartz, which varies in abundance in different parts. Both chlorite and feldspar show parallel arrangement and elongation along the general direction of the cleavage. The quartz is in irregular grains either disseminated with the other minerals or bunched in spots. Through this fine-grained matrix are scattered somewhat larger grains of siderite. These vary in size from mere specks to perhaps one-tenth of an inch in diameter, and are abundant in all phases of the rock. Some have rhombic outlines and consist of single crystals, but most of them are irregular and consist of several individual crystals. Near the surface the siderite is oxidized to limonite and forms yellowish brown specks of ocher. Locally also the ocher is concentrated along cracks and in small openings. In some phases of the rock siderite in small irregular grains is disseminated through the matrix, along with feldspar, chlorite, and quartz.

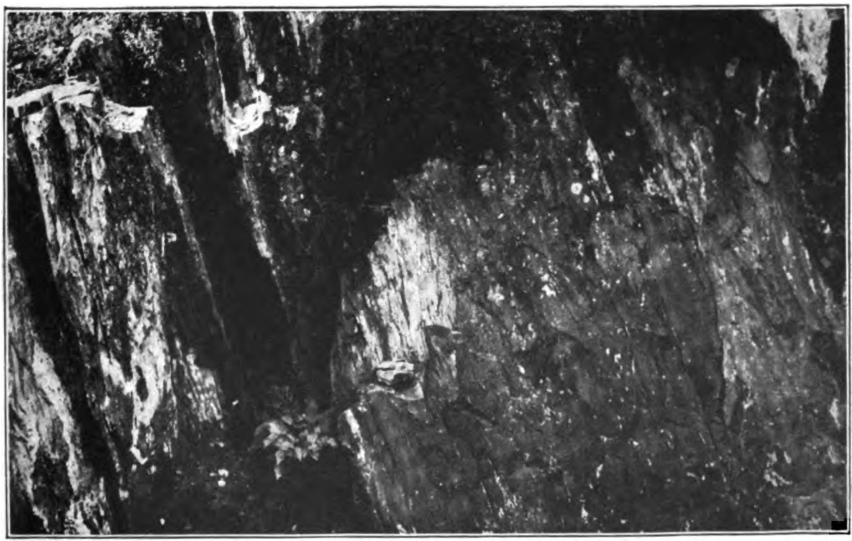
Besides grains and little bunches of siderite, other minerals such as quartz, magnetite, and chlorite are found in the rock. Magnetite is very abundant locally, and although it is generally distributed through the rock it may be entirely absent in some places. Some magnetite grains have crystal outlines, while others are irregular. Quartz usually does not occur in large grains, but bunches of small grains are numerous.

---

[68] Grout, F. F., Contribution to the petrography of the Keweenawan: *Jour. Geology*, vol. 18, pp. 633-657, 1910.



A. OUTCROP OF CHLORITIC SCHIST NEAR THE STATION AT RANDALL, MORRISON COUNTY
PHOTO BY CARL ZAPPFE



B. CHLORITIC SCHIST OUTCROPS AT RANDALL SHOWING CLEAVAGE
PHOTO BY CARL ZAPPFE

UNIV. OF MICH.

Chlorite generally is evenly disseminated but locally it occurs in bunches. Small grains of muscovite are found disseminated in much of the rock.

While all the rock is chloritic schist, there are local minor variations in the composition, color, and texture, as already indicated. At several points, nodular light-colored brownish masses are found which consist of quartz, feldspar, and siderite, but contain no chlorite or magnetite while elsewhere magnetite grains are closely spaced. The variation in magnetic attraction in the vicinity of Randall is attributed to this abundance of magnetite in the chloritic schist.

The Randall exposures are directly on the line of the southwest extension of the Cuyuna range. The rock is probably continuous with the chlorite schists which have been found to be so abundant in association with the iron-bearing formation in various parts of the Cuyuna range. In general appearance and composition the rock at Randall resembles closely the chloritic schist found in many of the Cuyuna range mines.

In section 3, T. 130N., R. 30W., about three miles east of Randall there are a few small exposures of chloritic schist which might readily be mistaken for boulders. They are located in the woods near the center of the section, just east of a little-used north and south wagon road that runs along the quarter line.

While most of the outcrops consist of dark green or grayish green chloritic schist, some of them have small bands of a gray porphyritic rock with large phenocrysts of white feldspar. Such bands are enclosed between chloritic schist, and there is a complete gradation between the two, showing that the chlorite schist is a dynamically metamorphosed phase of the porphyry. The direction of the cleavage is similar to that in the exposures near Randall.

About two miles north of Little Falls, Little Elk River empties into Mississippi River. Outcrops of gray slate and phyllite occur on both sides of this stream, the easternmost of the exposures being about 500 feet above its mouth. They extend along the stream for about 700 feet and within this distance several folds are found. The outcrops show beautifully both cleavage and bedding, and the relation between the two can be determined in the individual outcrops. The general strike of the bedding is about N. 50° E., while the dip varies on account of the folding. The strike of the cleavage varies between N. 32° E. and N. 61° E. The dip of the cleavage planes varies in the individual folds, but is in general about 75° southeast.

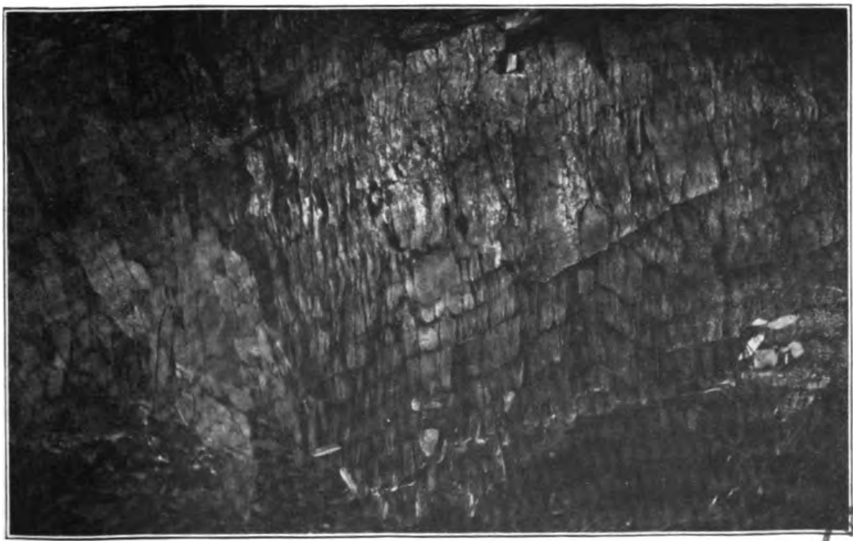
The exposures consist mainly of finely crystalline phyllite, most of which shows fine lamination parallel to the bedding. The rock is made up of fine quartz and biotite which vary in relative abundance in different layers. In some of the exposures, massive graywacke beds are interlayered with finely laminated, more highly micaceous phyllite beds. All the beds show cleavage, but the micaceous layers show it more perfectly. Thus the relation between the cleavage and the axial planes and pitch of the folds can be readily seen, and the relation of these folds to the major structure determined. The pitch of the folds is to the southwest, while the axial planes dip to the southeast, indicating that the folds are situated on the south limb of a major anticline.

In the city of Little Falls, a small island (Mill Island) occurs in Mississippi River just below the dam. (Plate VII A.) The shores around the northern half of this island consist of continuous outcrops of slate and phyllite, most of which are gray and finely micaceous. Although considerable recrystallization has occurred, the bedding is still plainly visible both on account of fine lamination and on account of an interlayering of beds of different materials. Some beds are quartzose while others are argillaceous and micaceous, the latter, however, being much the more abundant.

The beds are flexed into a number of minor folds all trending in a general northeast-southwest direction diagonally across the island. The strike of the bedding is approximately N. 30° E., parallel to the folds, while the dip varies. The schistosity is fairly regular, in general striking approximately parallel to the bedding and dipping at angles varying between 75°NW. and 75°SE. The relation of the cleavage to the bedding is clearly shown in some of the minor folds. (Plate VII B.)

The rock on Mill Island is principally dark gray, finely micaceous slate and phyllite, some portions of which are argillaceous and some quartzitic, the different phases being interlayered. Some beds are massive and quite uniform in texture, and show the bedding only by fine color lamination, while in other beds thin layers of fine argillaceous slate are interbedded with more coarsely crystalline quartzitic or micaceous phyllite. The cleavage cuts across all the laminae indiscriminately. The rock is composed of biotite and quartz with probably a considerable percentage of white mica in fine sericitic flakes. In the fine-grained slaty layers, sericite is very abundant, and distinctly visible mica flakes are almost absent, while in the coarser layers numerous fine flakes of biotite occur, disseminated in a quartzose or sericitic ground-mass. Other minerals which occur locally in the slate and phyllite are ottrelite, garnet, amphibole, and chlorite. Ottrelite occurs as small, scattered, thin, shiny black plates lying parallel to the cleavage in some of the phyllite layers, and garnet also occurs locally in the phyllite in tiny, disseminated crystals. Both are rare. Garnet, amphibole, and chlorite, however, are found more characteristically in a number of elongated, lens-shaped, concretion-like masses which occur interlayered with the slate and phyllite. Some of these masses are five or six feet long and a foot or more thick. They consist of a hard, dark, siliceous ground-mass in which are embedded

A. SLATE AND PHYLLITE OUTCROPS ON MILL ISLAND AT LITTLE FALLS, MORRISON COUNTY



B. SLATE OUTCROP AT LITTLE FALLS SHOWING THE RELATION OF CLEAVAGE TO BEDDIN

UNIV. OF MICH.

abundant fibrous, black amphibole or dark red garnet with associated dark green flakes of chlorite. The amphibole crystals range up to one half of an inch in length and show no regularity in their arrangement. The garnet crystals average about one eighth of an inch in diameter, being much larger than those disseminated through the phyllite. Chlorite is commonly associated with it, and appears to be an alteration product of it. Rarely, garnet and amphibole are found together in the same concretion-like lenses, but commonly they are in separate lenses. Ottrelite also is often distinctly associated with these lenses. It does not occur within them, however, but in the phyllite or slate layers along their borders. Amphibole, on the other hand, is found only in the concretion-like masses, and not in the slate and phyllite. The origin of the concretion-like masses has not been determined.

Another outcrop of gray slate and phyllite similar to that at Little Falls is found on Swan River near Ledoux in the SE¼ of SE¼ of section 4, T. 128N., R. 30W., about 7 miles southwest of Little Falls. The exposures are on both sides of the stream near the water level and are entirely covered during high water. They are found just east of the bridge between sections 3 and 4. The rock is a finely crystalline micaceous, argillaceous, or quartzitic phyllite with well-developed cleavage striking about N.20°E., and dipping from 57° southeast to vertical. The bedding is shown by fine banding and lamination which is cut across by the cleavage lines. It strikes in general N.25°E. and dips 75°N.

Upham[64] mentions the occurrence of another outcrop of slate on Swan River in section 1, T. 128N., R. 20W., about 2½ miles below the outcrop just mentioned. It is said to crop out in the bed of the stream but was not found by one of the writers (Johnston) who visited the locality.

Scattered outcrops of garnetiferous, staurolitic mica schist are found on both banks of Mississippi River at intervals between the mouth of Swan River, about 4 miles south of Little Falls, and a point about one half mile south of the Minneapolis, St. Paul, and Sault Ste. Marie railroad bridge in section 32, T. 128N., R. 29W. The best exposures are on the west bank, but good exposures occur on the east bank also. Locally they extend partly or entirely across the river, forming rapids.

The exposure farthest north is on the west bank of the river at Pike's Rapids, a short distance below the mouth of Swan River in section 7, T. 128N., R. 29W. Southward from this locality exposures are found at Cash's Rapids in section 20, T. 128N., R. 29W. and at various points between Cash's Rapids and the railroad bridge above mentioned. Below the bridge several exposures occur as far south as Blanchard's' Rapids, where are found the outcrops of gabbro, already described. (See page 51.) In one small outcrop about 1,000 feet south of the bridge, a very quartzitic phase of the schist is cut by a narrow dike of dark hornblende rock.

---

[64] Upham, Warren, The geology of Crow Wing and Morrison counties: *Geol. and Nat. Hist. Survey of Minn., Geol. of Minn.*, vol. 2, 1882-1885, p. 600.

Most of the schist exposures are near the river's edge, and very few extend far above the level of the water on the river bank. At one or two localities, however, as at the Minneapolis, St. Paul, and Sault Ste. Marie railroad bridge, fairly large exposures are found. Because of the highly metamorphosed state of the rocks, it is only in the larger exposures that it is possible to determine the attitude of the bedding and its relation to the schistosity. Thus at the railroad bridge the schist, although strongly metamorphosed, shows interlayering of coarsely crystalline micaceous phases with finer grained quartzitic phases indicating bedding. The layers in this exposure strike N.8°E. and dip 57°NW. while the schistosity strikes N.15°E. and dips 52°NW. In the outcrops at the other localities visited, it was not possible to distinguish the bedding. The schistosity, however, was found to be perfect and fairly regular. Thus at Pike's Rapids, below the mouth of Swan River, the strike of the cleavage is N.30°E. and the dip is 65°NW., while at Cash's Rapids the strike is N.30°E. and the dip 60°NW. Above Blanchard's Rapids, south of the railroad bridge in the last schist exposure downstream, the strike of the schistosity is about north and south and the dip is 65°W. Thus there appears to be a gradual turning of the direction of schistosity from a strike of N.30°E. to nearly north and south on going southward.

The schist in all the exposures is very similar, being a micaceous or quartzose micaceous schist with abundant crystals of garnet and staurolite scattered through it. The schist, while in general similar to that at Little Falls, is much more coarsely crystalline and is more uniform in character, consisting of intermixed quartz grains and biotite flakes, the latter parallel to the schistosity. The fine interlayering which is common in the slate and phyllite at Little Falls has here been entirely obliterated, due to recrystallization. Garnet and staurolite are both abundant and occur throughout the rock. The garnet crystals are small, usually averaging about one twentieth of an inch in diameter, but the staurolite crystals range up to an inch in length and one half inch in width and frequently show cross-shaped twins. The staurolite and some of the garnet also contains abundant included quartz grains and occasional biotite flakes. The outline of the staurolite crystals as seen under the microscope is very irregular and indicates that the staurolite has grown at the expense of the quartz and biotite. The quartz grains included in the staurolite crystals are smaller than those in the remainder of the rock, showing they have probably been partly resorbed to form staurolite. A few staurolite crystals contain included garnet crystals also. Ottrelite which is present in the rocks at Little Falls has not been found in these schists. Probably it has disappeared during the more intense metamorphism which the schists have suffered. The paragenesis of minerals in the formation of garnetiferous and staurolitic schist from the original shale appears to be in the following order: quartz, biotite, ottrelite, garnet, staurolite.

It seems beyond question that the slate and phyllite on Little Elk River and at Little Falls, and the garnetiferous and staurolitic schists on Mississippi River represent different stages in the metamorphism of the same original rock. The metamorphism seems to have become more intense on going southward, due probably to the presence of the great granite mass in the St. Cloud region against which the sediments were crushed. This fact would seem to indicate that much of the granite in this region was present before the deformation of the sediments took place, probably being pre-Keweenawan in age. The alternative hypothesis is that the granite is later in age, and that the metamorphism of the sediments was due to the intrusion of the granite. It does not seem likely, however, that the metamorphic effect of such an intrusion should be felt for many miles away from the contact, especially in an argillaceous sedimentary rock. Besides, the minerals developed are characteristic of dynamic metamorphism and not of contact metamorphism.

Hall[65] notes the probable occurrence of schist in the northern part of Benton County, and on the basis of this Van Hise and Leith[66] have extended the upper Huronian slate area into Benton, Sherburne, and Stearns counties, while the granitic rocks of this region have been mapped as Keweenawan intrusives. The data on which the mapping of this schist was based are not available, so that the character and extent of the schist are not known.

CROW WING, CASS, AND AITKIN COUNTIES

In the region north of the Cuyuna district and west and southwest of the Mesabi district, no rock outcrops are definitely known, although several have been reported from different localities.

An outcrop of crystalline limestone is frequently mentioned as occurring in NW¼ of SE¼ of section 29, T. 137N., R. 28W. south of White Fish Lake in northern Crow Wing County. This supposed outcrop has been visited by the writers, who have come to the conclusion that it is a large glacial boulder. The rock rises about 15 feet above the ground and is about 20 feet by 30 feet at the base. It has a rather jagged outline and consists of light gray to pink crystalline limestone with numerous small masses and thin layers of chert. Certain layers are somewhat argillaceous and sericitic, others are quartzitic. Drilling operations not far from this locality indicate that the glacial drift in this region varies in thickness from 200 to 300 feet. It appears improbable that there should be such extreme irregularities as would result in the occurrence of rock outcrops.

---

[65] Hall, C. W., Keewatin area of eastern and central Minnesota: *Bull. Geol. Soc. Amer.*, vol. 12, pp. 343-376 (map), 1901.

[66] Van Hise, C. R., and Leith, C. K., *op. cit.*, Pls. I and XIV.

Occasional references are seen in the literature[67] to an outcrop of rock in Cass County, reported as occurring along the northern edge of T. 142N., R. 27W., on Boy River, one or two miles below Boy Lake. The lithological character of the rock is not known, but it is presumed to be quartzite. The writers have not seen the outcrop, nor have they seen any person who knows definitely of its existence.

Quartzite outcrops are found near Dam Lake, Aitkin County, at two localities, one in the SE¼ of section 34, and the other in the NW¼ of section 35, T. 47N., R. 25W. The rocks composing the exposures are very similar in both localities, being hard, coarse, light gray to pink vitreous quartzite. Much of the rock is very coarse, being fine conglomerate or grit rather than quartzite. The particles composing it range up to one fifth of an inch in diameter, and all are distinctly rounded. They consist almost entirely of glassy quartz, some being perfectly transparent and colorless while others are bluish white opaline. They are all firmly cemented so that the rock breaks across the fragments rather than around them.

At both localities, several small rounded exposures protrude just above the soil. The rock is very massive and shows no trace of bedding. Even banding due to interlayering of coarser and finer material is apparently absent. A few joints cut across the outcrops and some of them may be separation planes indicating the bedding, but their character is very doubtful. Winchell,[68] who visited these outcrops, states that the exposure in section 34 shows an unmistakable bedding plane striking N.60°E. and dipping S.30°E. at an angle of 25°. This observation was not confirmed by an examination of the outcrops made by the writers. The line which connects the two outcrops, however, and the extension of which to the southwest passes over other occurrences of quartzite found by drilling, has a direction of N.50°E. which corresponds fairly well with the general strike of the sedimentary beds throughout the Cuyuna district. The general dip of these beds also is to the southeast, but at a very steep angle. It does not seem improbable, therefore, that the quartzite bed has a general northeast-southwest strike and a southeasterly dip, although there is apparently nothing in the individual exposures to indicate this structure.

---

[67] Upham, Warren, The geology of Cass County and of the part of Crow Wing County northwest of the Mississippi River: *Geol. and Nat. Hist. Survey of Minn., Geol. of Minn.*, vol. 4, 1896-1898, p. 65.

[68] Winchell, N. H., The Cuyuna iron range: *Econ. Geology*, vol. 2, pp. 566-567.

PINE, CARLTON, AND SOUTHERN ST. LOUIS COUNTIES

Several large areas of outcrops of metamorphosed sedimentary rocks are found in the northwestern part of Pine County, south, east, and northeast of Denham, these being the southernmost outcrops of this type of rock in eastern Minnesota. The rocks are principally mica schists, but hornblende schist, quartzite, and limestone occur also.

The largest area of outcrops is that through which the Minneapolis, St. Paul, and Sault Ste. Marie Railroad passes east and northeast of Denham. The principal exposures are in the eastern half of section 19, T. 45N., R. 20W., but some are found also in the western part of section 20 and in the southeastern part of section 18. The railroad cuts through or passes over most of the outcrop.

The rock throughout this area is quite uniform, being a quartzose mica schist. It varies slightly, however, in texture and in the relative amounts of mica and quartz which it contains in different parts. Locally it is fine-grained and quartzitic, consisting of sugary quartz with abundant fine scattered biotite flakes parallel to the schistosity. Elsewhere the quartz is present in minor amount and the mica is more coarsely crystalline, producing a very marked schistosity. Local layers consist almost entirely of mica. Small disseminated crystals of garnet are scattered throughout the rock, but are more abundant in the coarsely micaceous phases. The rock in general is dark gray, the mica being mainly biotite; but white mica is intermixed with it.

Schistosity is strongly developed throughout the area so that in general it obliterates the bedding. Locally where the bedding can be distinguished by the faint interlayering of the quartzitic with the more coarsely micaceous phases, it appears to be in general parallel to the schistosity. The schistosity is quite regular in strike in the different outcrops throughout the area, being about east and west or slightly north of east. The dip, however, varies considerably in different places. In the southern part of the area it is to the north at angles varying in general between 30° and 70°. In the northern part of the area, however, both northerly and southerly dips are found. Locally the schistosity is almost horizontal.

About a mile southeast of Denham is one of the most interesting groups of outcrops of metamorphosed sediments in east central Minnesota. The exposures occur principally in the E½ of SE¼ of section 25, T. 45N., R. 21W., but extend for short distances into the adjacent parts of section 30 on the east and section 36 on the south. An irregular depression with low bluffs along it runs in a southeasterly direction through this area. It varies from 200 feet to 400 feet in width, and has the appearance of being a small abandoned stream valley. The rock outcrops are found along the low bluffs on both sides of the depression. The area is wooded, the center of the depression being swampy.

The most northerly outcrops on both sides of the depression consist of hornblende schist. To the south of these, a large outcrop of quartzite is found on the west side and an outcrop of mixed quartzite and crystalline limestone on the east side. South of the quartzite on the west side are exposures of hornblende schist, followed by more quartzite and finally mica schist, while on the east side opposite to these are outcrops of mica schist and of a dark fine-grained igneous rock. The strike of the beds throughout is approximately east and west, while the dips vary 15° or 20° on either side of vertical. The dip of the cleavage of the schistose rocks is in general to the north at somewhat lower angles. In the schistose rocks the recrystallization has almost entirely obliterated the bedding, but in the quartzite and limestone the bedding is well marked. Locally rocks of different character are found interlayered.

The principal exposures consist of quartzite which has suffered considerable metamorphism. It is light-colored gray, pink, or brown and is medium coarse-grained. Tiny pebbles, generally of light blue quartz, are abundantly scattered through the rock, in some places making up the larger part of the mass and forming a fine conglomerate or grit. They range in diameter up to about one fifth of an inch, although locally pebbles an inch and a half or more in diameter are found. In places fine and coarse material occur interlayered in thin beds. The quartzite has undergone considerable recrystallization so that abundant muscovite is developed throughout. Some parallel arrangement is noticeable in the muscovite, but this is not prominent enough to produce a marked schistosity. The muscovite, although generally fine, occurs in distinct flakes.

The crystalline limestone is associated with the quartzite and resembles it in appearance. It is pink to light gray in color and finely crystalline. Muscovite occurs in it abundantly in fine disseminated flakes or is segregated into thin discontinuous streaks. Some phases of the limestone are dark gray and contain thin layers consisting largely of dark hornblende. The laminae of both muscovite and hornblende are developed parallel to the bedding, suggesting that they were formed by the recrystallization of impure limestone layers.

The hornblende schist is dark grayish green and is generally coarsely crystalline when composed mainly of hornblende and finely crystalline when it contains considerable quartz. It has a well-developed cleavage which is especially prominent in the more coarsely crystalline phases. The hornblende is dark green and fibrous. Biotite is generally associated with it and in places muscovite also occurs.

PLATE VIII

A. OUTCROP OF SLATE AND PHYLLITE ON SPLIT ROCK RIVER, SOUTHWESTERN CARLTON COUNTY, SHOWING HORIZONTAL SCHISTOSITY

B. OUTCROP OF SLATE AND PHYLLITE ALONG THE RAILWAY NORTHEAST OF DENHA PINE COUNTY, SHOWING PARALLEL JOINTING

UNIV. OF MICH.

The mica schist is light to dark gray. In places it consists mainly of muscovite with subordinate quartz, and then shows marked cleavage and fine lamination parallel to the cleavage. The cleavage faces present a silvery sheen due to aggregates of parallel muscovite flakes. In other places, quartz predominates while both muscovite and biotite occur in abundant fine flakes. In the latter phase the bedding is still frequently recognizable, cutting across the schistosity or parallel to it. The muscovite schist is commonly associated with the crystalline limestone beds, frequently being interlayered with limestone. The quartzose mica schist with abundant biotite is similar to that exposed along the railway east of Denham.

In Carlton County, abundant outcrops of slate, graywacke, phyllite and mica schist occur in the valleys of Kettle, Moose, and St. Louis rivers and their branches, the area of outcrops extending in a general northeast-southwest direction across the county. Many exposures are found directly on the banks of streams, having been cut into by the streams during the process of erosion. Other exposures, however, occupy higher areas, in places forming prominent ridges rising above the general level and elsewhere occurring as low, flat outcrops. The ridge-like exposures are very characteristic. In some localities, as at Carlton and near Atkinson, many parallel rock ridges cover considerable areas. Some of these are 40 or 50 feet high and many hundred feet long. Nearly all of them have a general direction ranging between east-west and northeast-southwest, roughly parallel to the cleavage.

The most southwesterly outcrops of metamorphic rocks in Carlton County are those along Split Rock River, a western tributary of Kettle River. A high cliff of mica schist about 900 feet long is exposed on the south side of Split Rock River in the NW¼ of NE¼, section 29, T. 46N., R. 21W. It rises abruptly from 5 to 30 feet above the stream, trending approximately east and west. Small exposures appear at intervals west of the main cliff in the bed of the stream for a distance of several hundred feet. The rock is made up of alternate bands of fine and coarse grained quartz mica schist associated with some dark graphitic schist. Small grains of pyrite and quartz lenses occur in places. The finer grained varieties are finely plicated and consist mainly of mica, while the coarser grained varieties are rich in quartz. The average strike of the schistosity is about N.80°E. and the dip varies, due to minor folds, but is in general to the south at a low angle. The bedding where it can be observed is approximately parallel to the schistosity.

An outcrop of mica schist and phyllite similar to that described above occurs in the SE¼ of SE¼ of section 21, T. 46N., R. 21W. on the south side of Split Rock River. The outcrop begins at the east line of the section and extends westward about 1,100 feet. The eastern part appears in scattered patches above the soil and the western half stands as a vertical cliff from 2 to 10 feet above the water. The bedding in this outcrop is well marked because of the alternation of more or less massive layers rich in quartz, with finely plicated layers consisting principally of mica. The strike of the bedding is about N.75°E. and the dip 30° to the south. Locally minor folds are found, which pitch westward at a low angle, and the axial planes of which dip southward indicating that they are drag folds on the south limb of a larger anticline.

The outcrops along Split Rock River are the only exposures of schist or phyllite found in Carlton County west of the main valley of Kettle River. On Kettle River itself abundant outcrops are found at intervals, almost from its source, southward through southern Carlton County and into Pine County. The most northerly of these outcrops is said to occur near Kettle Lake. It is reported that slate was encountered during the construction of the drainage ditch heading out of Kettle Lake in the SW¼ of SE¼ of section 18, T. 48N., R. 19W. The slate is said to have been found in the bottom of the ditch a short distance from the lake. This has not been verified by the writers.

The first exposure south of Kettle Lake in the Kettle River valley is found in section 2, T. 47N., R. 20W., in the bottom and along the sides of the drainage ditch. In the SW¼ of NE¼ of this section, small exposures are found in the bottom of the ditch for a distance of about 500 feet, while in the NE¼ of SW¼, beginning about 150 feet southwest of the center post and bearing a little west of south, rock is exposed continuously in the ditch and along the sides for about 700 feet. The maximum width of the exposure east and west is about 800 feet.

The rock in both localities is made up of alternate bands of slate and graywacke. The slate is dark gray to greenish black, very fine grained, with well-developed cleavage. The bedding is brought out clearly by difference in color due to the variation in the fineness of the material. The graywacke is light gray and fine-grained, with a few small scattered pyrite grains. The general strike of the bedding is about N.75°E. and the dip varies in short distances, due to the presence of minor folds which pitch at low angles eastward. Quartz stringers occur along the crests and troughs of the minor folds and die out along the limbs. The strike of the cleavage is approximately parallel to the bedding and the dip is 73° to the south. The relations of the folds and cleavage indicate that this outcrop is on the south limb of a larger anticline.

Near the south line of the SE¼ of SW¼ of section 21, T. 47N., R. 20W., two long, narrow, parallel rock ridges rise on the west bank of Kettle River and trend southwestward. The larger or south ridge is 60 feet wide by 275 feet long and rises about 20 feet above the stream. The north ridge is about 10 feet wide and 50 feet long, and is only a few feet above the stream. The rock is a dark gray, fine-grained, dense hornblende schist which weathers to a rusty brown. Locally it has a marked schistosity, and fine mica flakes are developed along the cleavage planes. The strike of the schistosity is about N.20°E. and the dip is 80° southeastward. Much of the fresh rock has the general appearance of being dynamically metamorphosed, fine-grained, dark igneous rocks, but the original textures have been obliterated and are not recognizable in the field.

The next outcrop of schist to the south in the Kettle River valley is near the mouth of Silver Creek in the SW¼ of NW¼ of section 16, T. 46N., R. 20W. About 30 feet from the mouth, in the bed of the brook, a light gray, fine-grained phyllite crops out and is cut by a quartz vein trending a little east of north and standing almost vertical. This was explored for gold about 30 years ago, and a pit 10 feet by 10 feet was sunk on it to a depth of about 30 feet.

The formation outcrops again on the west bank of Kettle River about 130 feet below the mouth of Silver Creek, making a vertical cliff 15 to 20 feet high for a distance of about 140 feet along the river. The bedding is brought out very clearly by the difference in the coarseness of the original sediments, giving lighter and darker bands. While most of the rock is light gray, fine-grained micaceous phyllite, portions of it are highly calcareous and other portions more siliceous. On the weathered surface, the interlayering of calcareous portions with siliceous portions is clearly shown. The general strike of the bedding is about N.70°E. and the dips vary from 9° to 17° to the south, due to minor folding. These minor folds pitch eastward at an angle of about 15°.

Somewhat over a quarter of a mile below the above outcrop, or about the west central part of the NE¼ of SW¼ of section 16, T. 46N., R. 20W., on the west bank of Kettle River, near the water's edge, is an exposure of light yellowish gray, finely laminated micaceous phyllite. The rock is badly weathered and soft. It is exposed for about 100 feet. The strike of the schistosity is about N.45°E. and the dip varies. At the south end of the outcrop it is 25°N., while in the central and northern parts it is 45° to the south.

At this locality, an outcrop of the so-called "Hinckley" sandstone is reported,[69] but was not found by the writers.

In the NE¼ of section 22, T. 46N., R. 20W., several outcrops of dark, fine-grained hornblende schist occur as ridges on both sides of Gillespie

---

[69] Winchell, N. H., The geology of Carlton County: *Geol. and Nat. Hist. Survey of Minn., Final Rept.*, vol. 4, 1896-1898, Pl. 56 and p. 16, 1899.

Brook. At the center of this quarter section, on the north side of the brook, is a large ridge trending about east and west. It is about 250 feet wide and 800 feet long, and rises from 5 feet to 25 feet above the stream. In part it is covered by a thin mantle of soil and loose blocks. The rock is greenish gray, fine-grained, sericitic, hornblende schist. Small specks and blotches of sericite cover the cleavage surfaces. The schistosity is well developed throughout, striking about N.54°E. and dipping 35°SE.

About 600 feet north of this outcrop several small low ridges of the same kind of rock crop out. The strike of the schistosity is N.75°E. and the dip is 19°S. About 400 feet southwest of the center of the quarter section on the southwest side of the stream a triangular ridge rises from 6 to 15 feet above the stream. The rock is the same greenish gray schist. The schistosity strikes N.41°E. and dips 3° southeast. On the south side of this ridge is a fine-grained, gray, mottled rock with brown specks roughly parallel to a poorly developed schistosity. East of the above-mentioned outcrop on the south side of the brook, a long low ridge begins about 200 feet from the east line of the section and continues eastward parallel with the stream for about 300 feet in section 23. The ridge rises a few feet above the stream and is, for the most part, covered with soil. On the weathered surface the outcrops consist of a rusty brown, micaceous, schistose rock. The fresher material, however, is fine-grained gray schist with small rusty brown spots parallel to the schistosity. The strike of the schistosity is about N.75°E. and the dip 19°S. The rocks composing the group of outcrops in sections 22 and 23 are mainly fine-grained hornblende schists. All show well-developed cleavage and banding. They have somewhat the appearance of being dynamically metamorphosed dark igneous rocks, but the original texture is no longer recognizable and they are therefore grouped with the schists and slates. They resemble closely, however, many of the metamorphosed, fine-grained, dark, igneous rocks found in this part of Carlton County and may represent a more advanced stage of metamorphism.

In the SW¼ of SE¼ of section 21, T. 46N., R. 20W., about a quarter of a mile north of the mouth of Gillespie Brook, on the east bank of Kettle River, an outcrop of decomposed schist makes a cliff 10 to 30 feet above the stream, for a distance of about 400 feet. The rock is a badly weathered schist, reddish and yellowish green in color and very soft. It is broken into small irregular blocks by several intersecting sets of joints. The rock shows a fine lamination or color banding parallel to prominent, gently undulating, parting planes. Small flakes of sericite and quartz stringers lie parallel to the lamination. The color bands may be due to the original difference in the material of different layers, or it may be secondarily developed parallel to the parting planes. The strike of the parting planes varies from N.85°E. at the north end of the outcrop to N.60°E. at the south end, and the dip from 9°N. at the north end to 25°SE. at the south end.

About 700 feet south of the above exposure, on the west bank of the river, decomposed schist crops out in a vertical cliff about 20 feet high. The exposure extends for 150 feet along the stream. The rock is like that described above. At the foot of the cliff, however, it is less weathered and consists of light greenish gray schist. Near the top of this cliff is a rusty light green schist infiltrated with limonite. The rock shows undulating parting planes similar to those in the outcrop on the east bank of the river.

Just below the mouth of Gillespie Brook, Kettle River turns westward. About 500 feet west of this bend on the north side of Kettle River a low rock ridge can be traced by frequent small exposures from the bank of the river northward about 300 feet to an east-west road which crosses the river below Gillespie Brook. A small outcrop lies in the road about 125 feet farther west. On the river bank the rock forms a cliff about 15 feet high and is exposed for a distance of about 250 feet. Most of the rock in this exposure is the same rotted, light, rusty green schist as that occurring along the river above the mouth of Gillespie Brook, although some of the less decomposed material is clearly chloritic and sericitic schist. At the west end of the outcrop, however, a different type of rock occurs. It is not finely laminated and shows no color banding, but is a soft, decomposed, light yellowish green, fine-grained rock with conchoidal fracture. Judging from its structural relation to the schist, it is probably a dike or sill of decomposed igneous rock. The contact of this rock and the schist strikes N.40°E. and dips 47°SE., while the banding of the schist strikes about N.34°E. and dips 25°SE. The exposures in the road consist of decomposed, greenish brown schistose rock which appears to have been chloritic schist. The schistosity strikes about N.70°E. and dips 28°S.

The only other outcrop of greenish brown rotted schist occurring in this vicinity forms a bank 15 feet high on the south side of the above-mentioned road about 350 feet east of the mouth of Gillespie Brook, in the NW¼ of NE¼ of section 28, T. 46N., R. 20W. The strike of the schistosity is about N.70°E. and the average dip is about 50°S.

Black graphitic schist outcrops in a low mound about 600 feet southwest of the mouth of Gillespie Brook and about 300 feet from the south bank of Kettle River, in the NE¼ of NW¼ of section 28, T. 46N., R. 20W. This mound is about 50 feet wide east and west and about 80 feet long. A small cut 10 by 20 feet, and 6 feet deep at the face has been excavated in it. The rock has well-developed schistosity and shows crumpled and crenulated foliation planes along which graphite is developed abundantly. The strike of the schistosity is about N.85°E. and the dip about 35°S. Near the surface the parting planes are stained with limonite. Pyrite crystals and small cavities, from which pyrite has been dissolved, are disseminated through the schist. Quartz stringers occur in some places.

Below the outcrops of graphitic and other schist near the mouth of Gillespie Brook, no outcrops are found along Kettle River for a distance of about three fourths of a mile. Beyond this, however, a group of exposures occurs in the southwestern part of section 28 and the southeastern part of section 29, T. 46N., R. 20W., forming escarpments along the river. The main escarpment on the east side of the river begins in the NW¼ of SW¼ of section 28, about 300 feet east of the river, and continues with frequent exposures, southwestward across the southeast corner of NE¼ of SE¼ of section 29, into the SE¼ of SE¼ of section 29, where it forms a vertical cliff 20 feet high and about 350 feet long on the south side of a big bend which occurs in the river at this place. The outcrop varies in width from a few feet at the north end to 400 feet at the south end. Exposures also occur on the west side of the river about 600 feet north of the big bend near the south line of the NE¼ of SE¼ of section 29. A rounded hill of rock about 230 feet wide east and west and about 260 feet long rises from the water's edge to a height of about 30 feet.

The principal rock in this group of exposures is a dark greenish gray, banded, fine-grained, micaceous hornblende schist. There is an alternation of bands of coarser and finer grained material. The schistosity is parallel to the banding or lamination. Stringers and lenses of quartz and quartz and calcite, varying from a fraction of an inch up to several inches in thickness in places lie parallel to the lamination. Generally in the larger lenses the quartz occupies the middle zone with calcite on either side. Quartz and calcite also form thin films along the joint planes. Pyrite occurs abundantly as small stringers along the banding and joint planes, and as crystals disseminated through the rock. At the north end of the escarpment the banding and schistosity strike about N.75°E. and dip 40°S., and at the south end they strike about N.85°E. and dip 27°S. Gentle undulations occur between these points. At the outcrop on the west side of the river the strike of the banding and schistosity is about N.85°E. while the dip is to the south at low angles.

In the northeastern part of the NW¼ of NE¼ of section 32, T. 46N., R. 20W., a low narrow outcrop lies at the water's edge on the west bank of Kettle River. The rock consists of alternate layers of coarse- and fine-grained, light gray phyllite. The surface is stained a rusty brown.

The fine-grained layers are much contorted. Quartz lenses parallel to the lamination and schistosity are found in the fine-grained bands. The strike is about N.70°W. and the dip is to the southwest at a low angle.

About a quarter of a mile below the exposure in section 32, Split Rock River flows into Kettle River from the northwest. A precipitous cliff of rock forms the southwest bank of Split Rock River from its mouth up stream for a distance of about 300 feet. Below the mouth, the cliff continues southward along the west bank of Kettle River for about 1,200 feet. The rock is light to dark gray, fine-grained, micaceous phyllite. Alternations of fine-grained micaceous with coarser grained more siliceous layers bring out the original difference in the sediments. The bedding and schistosity are parallel and gently undulating. The finer grained layers are minutely crenulated. Small lenses of quartz occur locally parallel to the schistosity. A small pegmatite dike parallel to the schistosity is exposed for a few feet in a pit about 50 feet south of the mouth of Split Rock River. Several sets of intersecting joints cut the rock into polygonal blocks of various sizes. The average strike of the schistosity and lamination is about N.80°E. and the dip varies from 15° to 35°S.

A rock similar to that found at the mouth of Split Rock River is exposed over a large area in the center of the SE¼ of section 32, T. 46N., R. 20W. It outcrops along the west bank of Kettle River for a distance of about a quarter of a mile and extends westward from the river about the same distance. The outcrops occur on a burnt-over tract as three large, flat, irregular mounds or ridges. The rock is light to dark gray, fine-grained, banded mica schist and phyllite, with marked schistosity in general parallel to the banding. The more micaceous or finer grained layers are crenulated. Quartz occurs in lenses parallel to the schistosity and also in veins from a few inches to several feet wide cutting across the schistosity. These quartz veins strike about N.10°E. and stand vertically. The strike of the bedding and schistosity is about east and west and the dip varies from 3° to 25° south, due to the broad low undulations.

The phyllite and mica schist can be traced southward by frequent outcrops along the escarpment on the west side of the river to the southeast corner of section 32, T. 46N., R. 20W., where they form an overhanging cliff about 20 feet above the water. This cliff continues southeastward along the river for about 600 feet into Pine County, cutting across the northeast corner of section 5 and ending in the NW¼ of NW¼ of section 4, T. 45N., R. 20W. The average strike of the schistosity in this area is east and west and the dip is about 20°S.

Farther south along Kettle River in northern Pine County, a number of scattered exposures of phyllite and mica schist occur extending through section 4 and thence southward as far as the south line of section 9, T.

45N., R. 20W., below which point no schist outcrops are known on Kettle River. In the southwestern part of the SE¼ of NW¼ of section 4, T. 45N., R. 20W., and extending southward into the NE¼ of SW¼ of section 4, a long narrow outcrop of schist occurs on the east side of Kettle River. It forms a steep cliff along the river bank for about 400 feet and then extends southeastward as a high escarpment, a short distance from the river, for about 800 feet, with frequent outcrops. The rock consists of alternate layers of quartzitic and micaceous, light to dark gray phyllite and mica schist. The darker micaceous bands are crenulated, while the quartzitic layers are evenly schistose. Lenses of quartz, with scattered hornblende and garnet, occur parallel to the schistosity. Near the south end a vertical northwestward striking quartz vein about 10 feet wide cuts the schist. The strike of the layering of the mica schist is about east and west, and the dip varies from 2°N. to 30°S., due to minor folding.

About a quarter of a mile to the southwest, in the northeast corner of the SW¼ of SW¼ of section 4, T. 45N., R. 20W., are two small outcrops of mica schist on the west bank of Kettle River near the water's edge. The larger one is exposed for about 120 feet and rises from 2 to 5 feet above the river. The smaller one is exposed for about 10 feet at the water's edge. The strike of the schistosity is about N.80°E. and the dip is 18°S.

In the E½ of NW¼ of section 9, T. 45N., R. 20W., on the east bank of Kettle River, about 800 feet south of the Minneapolis, St. Paul, and Sault Ste. Marie Railroad bridge over Kettle River, an outcrop begins which continues southward along the river for about 650 feet. The outcrop lies at the water's edge. The rock is a light gray, garnetiferous, mica schist. Some layers are very siliceous and contain abundant small flakes of biotite and muscovite in a sugary quartz matrix. These alternate with layers in which the mica occurs in coarser folia and quartz is present in minor amount. Lense-like inclusions of sugary quartz containing abundant greenish black hornblende and some garnet are found parallel to the schistosity. The strike of the schistosity is about east and west and the dip varies from 20° to 30°S.

A similar schist outcrops in the south central part of the NE¼ of SW¼ of section 9, T. 45N., R. 20W., on the southeast bank of Kettle River for a distance of about 600 feet. The strike is N.80°E. and the dip is 30°S. This is the southernmost known outcrop of this series of rocks on Kettle River. About a mile and a quarter below it, sandstone blocks and boulders are abundant in the drift. With the exception of a small outcrop reported to occur near Willow River, however, there are no outcrops of the so-called Hinckley sandstone along Kettle River for more than 10 miles below the southernmost mica schist outcrop, and it is possible that the schist forms the bedrock over a part of this area.

In the central and eastern parts of Carlton County, east of the Kettle River valley, outcrops of schist, phyllite, graywacke, and slate are more abundant than in the Kettle River region. They extend as scattered exposures and groups of exposures from Moose Lake in the south central part of the county to Cloquet in the northeastern part. In some places outcrops cover many acres while elsewhere small isolated exposures are found. For the most part, however, the mantle of glacial till is thin and the bed rock is probably not far below the surface throughout this region even where outcrops are small and scattered.

At Moose Lake mica schist is found northeast, north, west, and southwest of the town along both the Minneapolis, St. Paul, and Sault Ste. Marie, and the Northern Pacific railroads. The scattered outcrops cover an area roughly 2 miles long and ranging up to perhaps 1,000 feet in width. In the NE¼ of section 20, T. 46N., R. 19W., the Minneapolis, St. Paul, and Sault Ste. Marie Railroad runs in a rock cut from a few feet up to 15 feet deep for a distance of about 2,000 feet. The rock is light to dark gray, finely to coarsely crystalline phyllite and mica schist. The lighter gray layers are siliceous and fine-grained, while the darker layers are rich in mica and are more coarsely crystalline. The micaceous layers show fine crenulation and give shining, glossy, cleavage surfaces. Quartz occurs in lenses parallel to the schistosity and also as veins and thin films along some of the joint planes. About 800 feet from the north end of the cut, a vertical dike of fresh, grayish black, fine-grained, massive, igneous rock about 11 feet wide cuts the schist, striking about N.75°W. At the contact with the schist, the rock is extremely fine textured but becomes coarser toward the center of the dike. The contact is sharp and the schist is hardened within a few inches of the contact and its schistose structure is destroyed. The schistosity shows low, broad, undulations along the walls of the cut. The average strike is about N.60°E. and the dip varies from 5° to 40°SE.

The phyllite and mica schists continue as a ridge southwestward from the railroad cut for about a mile, where they are cut through by the Northern Pacific Railroad in the NE¼ of NW¼ of section 29. The ridge lies between the tracks of the two railroad lines, and rises about 30 feet above the grade of the Northern Pacific Railroad. Small outcrops are abundant along it. To the southwest it is lower and gradually disappears beyond the Northern Pacific railroad tracks. In the rock cut on the Northern Pacific Railroad in the southeast corner of SE¼ of SW¼ of section 20, and in the northeastern part of the NE¼ of NW¼ of section 29, the rock is exposed continuously for about 500 feet on the northwest side of the railroad. It shows low, broad, undulations in the schistosity which has a general low dip to the east.

Just northeast of Moose Lake in the north central part of the NE¼ of NW¼ of section 21, T. 46N., R. 19W., is a low, rounded mound 50 by 60 feet, about 170 feet northwest of the Northern Pacific Railroad tracks. The mound consists of interlayered quartzitic and micaceous schists. The light gray siliceous layers are thicker than those in the rock forming the ridge northwest and west of Moose Lake; individual layers reach a thickness of 2 feet. The strike of the layering is about N.85°E. and the dip 15°S.

About one third of a mile farther northeast, an outcrop of mica schist occurs in the bed of a small stream in the north central part of the SW¼ of SE¼ of section 16, T. 46N., R. 19W. The rock is exposed for about 40 feet and is similar to that in the cut at Moose Lake. The strike of the layers is about N.42°E. and the dip is 6°SE. Loose boulders and irregular blocks of the same kind of rock occur abundantly in the drift for several hundred feet to the southwest.

The next important group of outcrops to the northeast is that near Barnum. At the railroad station and extending westward from it is a large flat area of irregular outline in which rock exposures are abundant. The area is in the western part of the NW¼ of section 1, T. 46N., R. 19W., the NE¼ and the northeastern part of the NE¼ of NW¼ of section 2, T. 46N., R. 19W., the southeastern part of the SE¼ of SW¼ and the southern part of the SE¼ of section 35, T. 47N., R. 19W. It rises as a small upland 3 to 10 feet above the surrounding low land, and in places forms a vertical escarpment along the borders. Parts of it are concealed by a thin veneer of soil. The rock is phyllite and mica schist. Thin layers of glossy, dark gray, micaceous rock with wavy cleavage planes are interbedded with heavy, massive, layers of fine-grained lighter gray graywacke. These massive beds are from 2 to 10 feet thick and some of them are highly calcareous. Scattered stringers and lenses of quartz parallel to the schistosity are abundant in the micaceous layers, and calcareous concretions or lenticular rusty brown cavities from which they have been dissolved, are found in some of the massive beds. The average strike of the bedding is about east and west and the dip varies from 0° to 35°S. Small drag folds pitching from 0° to 35° to the east are abundant in the micaceous layers. The outcrop as a whole appears to be on the south limb of a larger eastward pitching anticline.

About 5 miles west of north from Barnum on the West Branch of Moose Horn River, in the SW¼ of NW¼ and the NW¼ of SW¼ of section 15, T. 47N., R. 19W., black slate and associated altered diabase crop out along the river bed for a distance of about one half mile. The exposures are practically continuous for this distance and rise on either side of the stream from a few inches up to about 5 feet. The southern part of the outcrop is black carbonaceous slate, probably largely graphitic, the strike and dip of which vary in short distances due to minor folding. Large crystals of pyrite occur in it abundantly. A well-developed fracture cleavage has been superimposed on the slaty cleavage and is almost at right angles to it. The large structural feature indicated by the slate outcrop is a southward dipping monocline, with minor drag folds, forming the south limb of an eastward pitching anticline. The northern part of the outcrop consists of dark, grayish-green, medium-grained, altered diabase, containing abundant scattered pyrite. The contact of the diabase and slate is not exposed, but it seems probable that the diabase forms a large intrusion in the black slate.

About 6 miles northeast of Barnum near Mahtowa, a station on the Northern Pacific Railroad, are numerous exposures of schist and slate and some of dark igneous rock. They are found chiefly along Moose Horn River and its branches from Mahtowa northward to Park Lake. Throughout most of the region the bedrock where not exposed is comparatively near the surface.

In the NW¼ of SE¼ of section 8, T. 47N., R. 18W., in a meadow about 1,000 feet southeast of the center of the section, two pits, 100 feet apart, pass through a thin mantle of glacial drift into bed rock. The pits are 8 by 12 feet and are reported to be 30 feet deep. The rock consists of layers of a light gray and dark gray, fine-grained phyllite and slate, black carbonaceous slate, and grayish black, dense, finely laminated amphibole schist or amphibolite. Small quartz lenses and stringers of carbonate occur parallel to the cleavage. Crystals of pyrite are abundant. In the west pit the cleavage and lamination strike about N.77°W. and dip 16°S., and in the east pit they strike about N.70°W. and dip 85°N. About 700 feet northeast of these pits is another pit, partly filled, which has black carbonaceous slate on the dump.

In the northwestern corner of this 40-acre tract are several small, low, shattered outcrops of a light gray, fine-grained phyllite. No satisfactory observations could be made as to strike and dip.

Another outcrop of phyllite, slate, and amphibolite occurs in the northeastern part of section 8 in a low round knoll on the north-south line between the NE¼ of NE¼ and NW¼ of NE¼, about 80 feet south of the north line of the section. The knoll is 250 feet wide east and west and about 300 feet long, lying west of Moose Horn River. The outcrop is mainly fine-grained laminated amphibole schist, but includes some layers of finely micaceous phyllite and slate. The cleavage is well developed in the micaceous phases, but less so in the amphibolitic phases. Some micaceous layers show crenulated cleavage. The weathered amphibole schist, or amphibolite, is speckled with abundant minute spots of light brown ocherous limonite, the decomposition product either of ferrous carbonate or of some ferrous silicate. Some of the rock has a rusty brown color due to the abundance of limonite. The slate and phyllite layers are subordinate to the amphibolite layers. All are comparatively thin-bedded. The rock lies in a series of small anticlines and synclines forming a larger westward pitching anticline. The axis strikes about N.75°E. and pitches about 60°W.

About 250 feet southwest of the northeast corner of the SW¼ of SE¼ of section 5, T. 47N., R. 18W., two pits were sunk about ten years ago in black carbonaceous slate, probably largely graphitic. The pits are 10 by 15 feet, and about 30 feet deep. The north pit passes through 20 feet of black slate into a glossy, light gray, micaceous slate and phyllite. The strike of the schistosity of the black slate is N.70°E., and the dip is 26°S. The south pit was sunk on a quartz vein about 2½ feet wide. The vein strikes about north and south and stands vertically, while the schistosity of the slate strikes N.66°E. and dips 37°S. Pyrite occurs abundantly in the black slate as narrow stringers parallel to the schistosity and also as large cubical crystals, an inch or more along the side, which have grown without reference to the cleavage. In many cases the cleavage of the slate is shown by parallel lines cutting across the crystals of pyrite, and thin parallel folia of slate are frequently included within the pyrite crystals. This shows that the pyrite is secondary, having developed during or after the metamorphism of the black slate in the same manner that the staurolite crystals are developed in the garnetiferous schist of the Little Falls region. (See page 62.)

A small, low outcrop of black slate is found 450 feet south of the pits in the same 40-acre tract.

In the E½ of SE¼ of section 5, T. 47N., R. 18W., small exposures of black slate occur frequently on both sides of the northwest road and in the bed of Park Lake River. These outcrops are low and shattered. A small pit on the east side of the road, about 800 feet north and 300 feet west of the southeast corner of the section, was dug in black slate, as shown by the material on the dump. Much pyrite occurs in this slate along cleavage planes. About 50 feet east of the pit is a shallow trench, 2 feet wide, trending north and south, exposing the black slate for a distance of 60 feet. The rock is covered by only a few inches of soil. The cleavage strikes N.70°E. and dips 75°S. About 200 feet north of the pit on the west side of the road black slate crops out over a small area, while 400 feet farther northeast on the east side of the road, light gray micaceous quartzite or graywacke crops out along the east section line and continues into section 4. The rock is massive and in general has a poorly developed cleavage. The strike of the layering is N.70°E. and the dip is 50°S. Several small exposures of black slate occur a short distance north and northwest of this outcrop on both sides of the road.

In the SW¼ of NE¼ of section 5, T. 47N., R. 18W., farther northwestward along the road, black slate is exposed at frequent intervals for a distance of about 700 feet. The rock occurs in low ridges on both sides of the road and has also been exposed in the grading. The strike of the cleavage at the south end of this area is about N.75°E. and the dip is 40°S.; at the north end the strike is about N.75°E. and the dip is 75°S.

A number of outcrops of graywacke, slate, and phyllite occur along the west line of section 4, T. 47N., R. 18W. south of the west quarter corner. As has been mentioned, some of these extend westward into section 5 and most of them also continue for a short distance eastward into section 4.

An outcrop of light gray phyllite and black slate occurs near the center of section 4. It lies on the west side of the north-south road running along the east line of the NE¼ of SW¼ of the section. The outcrop begins at the northeast corner of this 40-acre tract (at the center of section 4) and continues southward along the road for about 800 feet. The outcrop extends westward from the road 50 feet at the north end of the outcrop, and 200 feet at the south end. It is a low flat exposure, the west margin forming a westward facing escarpment 6 to 8 feet above the general level of Moose River, which is a short distance west. The outcrop is made up of alternate layers of light to dark gray phyllite and black slate. The dark bands contain carbonate minerals and are mottled with small porous specks of limonite. The outcrop is a large anticline with small drag folds on both limbs. The strike of the axis is N.80°E. and the pitch is 20°E.

A number of scattered outcrops of light gray phyllite and dark gray slate occur in the E½ of NE¼ of section 4, T. 47N., R. 18W. The rock is badly broken and rises only a few inches above the soil. No satisfactory observations could be made on the attitude of the rock in most of the outcrops. Near the southeast corner of the NE¼ of NE¼ of the section, however, dark gray slate striking about N.86°E. and dipping 45°S. crops out in a low ridge about 200 feet long, east and west and about 60 feet wide.

Three and one-half miles north of east from Mahtowa near the center of NE¼ of SE¼ of section 1, T. 47N., R. 18W., is a small outcrop of light gray, fine-grained graywacke. The outcrop is broken and covered with loose blocks. No satisfactory observations could be made as to strike and dip.

Several rock exposures of varying size are found in the SE¼ of section 31, T. 48N., R. 18W. The northern and easternmost of these is a low outcrop of a light gray, medium-grained graywacke occurring near the center of the east-west line along the north side of the NE¼ of SE¼ of the section. The attitude of the graywacke is uncertain.

In the W½ of the quarter section, several outcrops are found consisting mainly of slate, phyllite, and graywacke. The most northerly of these is about 400 feet west and 350 feet south of the northeast corner of the NW¼ of SE¼ of section 31. It is 5 feet wide and 10 feet long and rises only a few inches above the surface. The rock is dense, light gray, fine-grained graywacke. The weathered rock is full of minute brownish yellow specks of limonite. The graywacke has a poorly developed schistosity, which strikes N.84°E. and dips 64°S.

About 400 feet southwest of this outcrop, a 3-inch vertical hole was drilled to a depth stated to be 330 feet. No accurate log was kept of the drilling, as far as known. The information available, however, and an examination of the core, indicates that the upper part of the hole is in dense, dark gray, finely micaceous graywacke and that below this, black, carbonaceous (probably largely graphitic) slate was encountered. The cleavage in both rocks is well developed. The cleavage surface of some of the black slate has a mottled appearance caused by small, scattered, shiny, black particles. The dip of the cleavage is 50°, probably to the south.

About 450 feet somewhat east of south from the drill hole there are several small outcrops of light gray, medium-coarse graywacke. In some there is a slight orientation of the flaky minerals producing a poorly developed schistosity. Similar rock in small scattered exposures is found about 1,000 feet west of this exposure in the southeastern part of the NE¼ of SW¼ of section 31.

In the western part of the SE¼ of SE¼ of section 31, T. 48N., R. 18W., about one third of a mile southeast of the drill hole, are several long, low, narrow, parallel ridges consisting of alternate layers of phyllite, slate, and graywacke. The ridges vary in length from 50 to 300 feet and in width from 10 to 50 feet, their longer axes being parallel to the strike of the rocks. The slate and phyllite are dark gray and occur as narrow beds from a few inches to a foot thick in the heavy-bedded, lighter gray, fine-grained graywacke. These rocks lithologically are similar to those south of Park Lake, which are described later. The strike of the bedding is N.53°E. and the dip is 42°SE. Minor drag folds in the slate pitch northeastward at low angles. The rocks appear to be on the south limb of a larger anticline.

About ten years ago, in prospecting for coal, two pits were sunk just west of the dwelling house of J. P. Peterson in the SW¼ of NW¼ of section 32, T. 48N., R. 18W. The larger pit is 350 feet south and 70 feet east of the northwest corner of this 40-acre tract, on the east side of Park Lake Creek. It is 15 feet by 20 feet, and 30 feet deep. In the bottom a 3-inch vertical hole was put down 80 feet. The pit is now caved and partly filled with water. The small pit, 75 feet to the south, is 5 feet by 5 feet and was sunk to a depth of 8 feet. The surface material is from 2 feet to 10 feet in thickness. The rock in both pits is black carbonaceous slate, much fractured and impregnated with pyrite and quartz. The more highly carbonaceous phases of the slate are dull, earthy, and soft. Other phases are harder and show slickensides in several directions. Some graphite in shiny films is developed along the slickensides and along fracture planes. On account of the caving and water, the attitude of the slate could not be determined. The cleavage in a piece of core taken from the larger pit shows a dip of about 45°. This dip is probably south, judging from the structure of slate outcrops nearby.

In the region south and southwest of Park Lake are extensive outcrops of slate and graywacke, covering considerable areas in sections 29, 30, and 31, T. 48N., R. 18W. The northernmost of these exposures are found on the south shore of the lake in the SE¼ of NW¼ of section 29. They rise about 10 feet above the level of the lake and slope out into the lake beneath the water. Near the shore they form several small, low rock islands. Most of the rock is massive, medium-grained, light gray graywacke, with small bands of fine-grained, darker, slaty material, with well-developed cleavage. Glacial grooves and striations trending N.60°W. are seen on outcrops of the coarser phases. The strike of the formation varies from east and west to N.70°W. and the dip varies due to minor folding. Drag folds show that the outcrops are on the north limb of an anticline.

About 350 feet south of the center of section 29, T. 48N., R. 18W., on the north-south road running southward from Park Lake, graywacke and slate exposures occur as low, narrow ridges crossing the road in an east-west direction. The width of the group of exposures where it crosses the road is more than a quarter of a mile, and it extends eastward into the W½ of SE¼ of section 29 for a maximum distance of 250 feet. The group is at the northeast end of a large area of exposures which continues from this point southwestward across the SW¼ of section 29, the southeast half of the SE¼ of SE¼ of section 30, the northwest half of NE¼ of NE¼ of section 31, T. 48N., R. 18W. Throughout this area exposures are more or less continuous. South of its west end, small scattered rock ridges occur for a distance of about 800 feet farther, being partly in the SE¼ of NE¼ and partly in the SW¼ of

NE¼ of section 31. The main belt of exposures consists of many parallel rock ridges of varying size. They range from 5 feet to 600 feet in width and from 10 to 2,100 feet in length, and rise above the surrounding soil from a few inches up to 15 feet. The ridges are separated from each other by lower marshy ground, the distance between the ridges varying from 20 feet to 400 feet. Their longer axes strike east-west or a few degrees south of east.

The outcrops throughout the area are made up mainly of alternate bands of medium coarse-grained graywacke and fine-grained slate. These bands vary in thickness from a fraction of an inch up to several feet; the graywacke is more abundant than the slate and occurs in thicker, more massive beds. Locally fine micaceous phyllite occurs where deformation has been somewhat more intense, or where shearing has taken place. The slate is darker than the graywacke and has a well-developed cleavage. Some of the coarser graywacke phases, also, show a slight schistosity. Small, elongated, nodules or concretions of calcareous material occur in broken bands in the graywacke, and appear as cavities on the weathered surface. Quartz occurs sparingly as stringers between the bedding in the minor folds and as thin films along some of the joint planes. Small grains of pyrite are abundant in the coarser material, and on weathering leave small cavities with a rusty stain. Several sets of joints cut the rocks into polygonal blocks of various sizes.

The rocks are folded into a series of small anticlines and synclines of several orders, with the axes at the crests and troughs horizontal or pitching up to 5° either to the east or to the west. The average strike of the axial planes is about N.77°W. From a study of the drag folds and the relation of cleavage to the bedding, it appears that the Park Lake series of outcrops forms a low flat anticlinorium.

A short distance south of the main Park Lake area of slate and graywacke outcrops is a small exposure of phyllite. It is located on the north side of the east-west road between sections 29 and 32, T. 48N., R. 18W., about 100 feet east of the southwest corner of the SE¼ of SW¼ of section 29, T. 48N., R. 18W. The rock is light gray, and on the weathered surface is mottled, the mottling being due to small cavities containing limonite derived from the weathering of some disseminated iron-bearing mineral. The schistosity strikes N.82°W. and dips 35°S.

Numerous outcrops of slate and graywacke are found in the region between Park Lake and Atkinson, most of them are ridges trending approximately east and west. The most westerly of these is about a mile south of east from Park Lake in the southeastern part of section 28, T. 48N., R. 18W. Two long, low, narrow ridges are situated along the east-west road on the south line of the NW¼ of SE¼ of section 28.

The south ridge, about 30 feet wide, lies about 200 feet west of the southeast corner of the 40-acre tract, and extends westward along the road for about 470 feet. Ten feet north on the roadside is a smaller ridge about 200 feet long and 25 feet wide. The outcrop in the road consists of gray, medium fine-grained graywacke cut into polygonal blocks, 1 to 4 feet long by intersecting joints. Cavities formed from the more easily weathered carbonate nodules occur in bands bearing about east and west. Locally there is a poorly developed schistosity striking N.80°W. and dipping 34°S. The outcrop north of the road is made up of alternate bands of fine-grained, dark gray slate and medium fine-grained, lighter colored graywacke. These bands vary in thickness from 2 inches to a foot or more. Single bands can be followed the entire length of the outcrop. The strike of the layers is N.88°W. and the dip 56°N.

About a mile east of the exposures in section 28, a series of more or less parallel east-west rock ridges occurs in the east central part of the E½ of SE¼ of section 27, T. 48N., R. 18W., and continues eastward across the central part of the SW¼ of section 26. The ridges vary up to 600 feet in length and from 10 to 300 feet in width, and rise from 2 to 20 feet above the intervening depressions. Prominent ridges are found on both sides of the east-west road leading to Atkinson, the largest being on the south side. The rock is slate and fine-grained graywacke occurring in alternate beds. The beds are from a fraction of an inch to 10 feet or more thick. The slate beds have well-developed cleavage and are darker than the graywacke. Some layers are calcareous. Much of the rock is finely mottled for a few inches below the weathered surface, due to an abundance of small specks of limonite. Carbonate concretions or nodules, or cavities from which they have been weathered out, are found in some of the graywacke bands. Spongy quartz with soft earthy limonite in the cavities, occurs as veins along some of the joint planes and also parallel to the bedding. The limonite is a weathering product of siderite and perhaps of pyrite. The average strike of the bedding is about east and west, and the dip varies from 30° to 70°N. due to drag folds. The strike of the cleavage is about east and west and the dip is about 70°S. These rock ridges are structurally on the north limb of a larger anticline.

The next group of outcrops to the east is west, north, and east of Atkinson. It extends from the east central part of section 26, T. 48N., R. 18W., eastward through the central part of section 25, the last outcrops to the east being in the east central part of section 25. The exposures form a belt of more or less parallel east-west trending ridges occupying an area about a mile long east and west and about one fourth of a mile wide. A few outlying exposures are found west and north of the main belt. The individual outcrops vary from mere knobs to ridges 600 feet long and 300 feet wide. Several of the ridges west of Atkinson are 10 to 30 feet high. The rock consists of alternate layers of light to dark gray graywacke, and dark gray to black slate. The beds vary in thickness from a few inches to several feet. The weathered phases are mottled with fine specks of limonite. Quartz veins and quartz siderite lenses are common along the axes of the small folds and pinch out along the limbs. The siderite locally has been entirely altered, and the lenses consist of a spongy mass of quartz and earthy limonite. Several pits have been sunk in prospecting for gold in different parts of the area where these lenses are abundant. In two pits in the northeast corner of the NW¼ of SW¼ of section 25, a small brecciated zone is exposed in the dark-colored slate. Quartz, siderite, pyrite, and some calcite cement the breccia and extend into the wall rock for several feet as stringers between the laminae of the slate. The rocks in the central part of the area lie in a series of folds, with smaller folds down to minute plications superimposed on their limbs. The axes of the larger folds strike about east and west, and are either horizontal or pitch at a low angle to the east. At the western end of the main belt of outcrops in the northeast corner of the NE¼ of SE¼ of section 26, there is a low, flat exposure about 250 feet east and west and 100 feet wide. The average strike of the beds at this place is about N.75°E. and the dip varies due to minor folding. The axial lines of the minor folds strike about N.85°E. and pitch 8°E. The rock is light gray graywacke, some of which shows well-developed cleavage. Locally tiny flattened particles of dark gray slate are embedded in the lighter colored graywacke. Another small outcrop in the western part of the main belt of exposures occurs on the northwest-southeast road in the southern part of the SW¼ of NW¼ of section 25. The strike of the beds is about N.85°E. and the dip is 80°N.

Outlying exposures of graywacke and slate occurring northwest of the main belt of outcrops form two long, low, narrow, parallel ridges in the SE¼ of NE¼ of section 26, and the SW¼ of NW¼ of section 25. The ridges extend east and west for nearly a quarter of a mile and vary from 20 to 80 feet in width. They rise only a few feet above the surrounding flat area. The rock is mainly light gray, mottled graywacke with a few thin interbedded layers of slate. The strike is about N.85°E. and the dip varies from 40° to 60°S.

An outlying exposure north of the main belt of outcrops at Atkinson occurs in the north central part of the SW¼ of NE¼ of section 25, forming two low, flat, parallel, east-west ridges. They are about 250 feet long and 50 feet wide. The rock is light gray, siliceous graywacke in heavy layers with thin interbedded layers of dark gray slate. The beds strike about east and west and dip 45°S.

About half a mile east of Atkinson on Black Hoof River, is the easternmost outcrop of graywacke and slate in this vicinity. It is located in the west central part of the NE¼ of SW¼ of section 30, T. 48N., R. 17W., and consists of several low knobs of fine-grained, light gray graywacke. The outcrop rises near the north-south road on the west side of this 40-acre tract and extends eastward for about 650 feet. Knobs occur on both sides of the river rising 8 to 10 feet above the water and sloping gently toward the east. The rock is in places schistose and is cut into irregular blocks by several sets of joints. Concretions or nodules of carbonate minerals occur sparingly. The beds strike east and west and dip south at a low angle.

The belt of exposures extending from Park Lake eastward through sections 28, 27, 26, and 25, T. 48N., R. 17W., which is described above, includes the principal rock outcrops of this region. A more or less parallel belt composed of fewer and more scattered exposures, occurs south of this larger belt, extending in an approximately eastward direction from the eastern part of section 34, T. 48N., R. 18W. through sections 35 and 36, T. 48N., R. 18W., into section 31, T. 48N., R. 17W. The exposures of the northern belt have structures indicating that in general they are situated on the north limb of a large anticline, those in the southern belt appear to be either near the crest or on the south limb of an anticline.

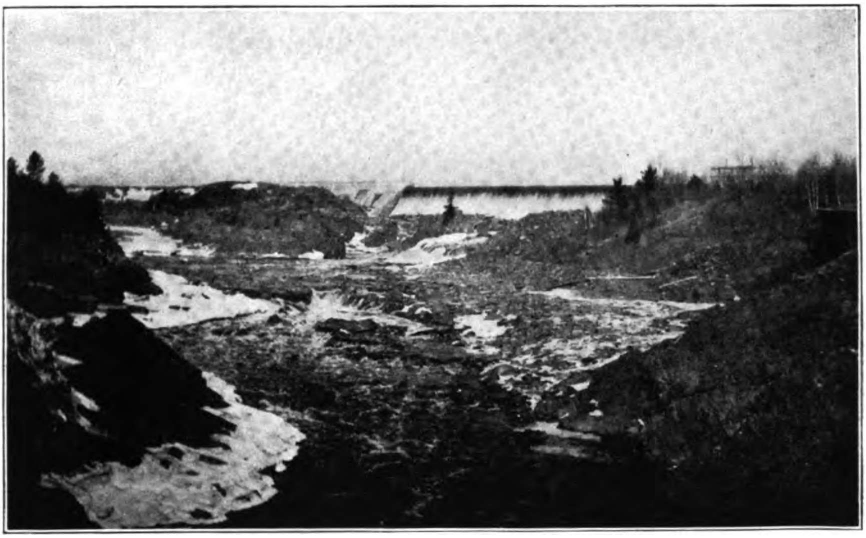
The westernmost of the exposures on the southern belt consists of a large irregular knoll of rock located in the east central part of the E½ of NE¼ of section 34, T. 48N., R. 18W., and extending for about 200 feet into the southwest corner of the NW¼ of NW¼ of section 35. The knoll is about 1,000 feet long east and west and about 800 feet wide north and south and rises about 60 feet above the surrounding country. It is made up of thick beds of a light gray, fine-grained graywacke separated by thin layers which are more slaty and darker in color. The slaty layers are micaceous and have well-developed schistosity. Locally they are crenulated and contain lenses of quartz parallel to the foliation. Intersecting sets of joints cut the rock into large irregular blocks, and some of the joints are filled with quartz. Lenticular depressions, stained black or rusty brown, from which nodules of carbonate minerals have been dissolved, occur parallel to the strike of the bedding in some of the coarser layers. The outcrop appears to represent an eastward pitching anticline, the strike of the axial line being about N.85°E. and the pitch 10°E. Small drag folds occur on both limbs of the anticline.

In the northeastern part of the SW¼ of NE¼ of section 35, T. 48N., R. 18W., just south of the north line and about 100 feet west of the Northern Pacific tracks, is a low glaciated ridge of phyllite. The ridge is about 150 feet long east and west and 75 feet wide, and rises a few feet above the surrounding meadow. Thick, light gray, fine-grained, arenaceous layers alternate with dark gray, slaty layers. Some of the slaty layers show a considerable development of fine mica along cleavage planes. Concretions of carbonate minerals are abundant in some of the layers. At the east end of the outcrop they are more resistant than the enclosing rock and stand out as tiny knots, while at the west end they have been dissolved, leaving rusty brown or black pod-like depressions. Several sets of intersecting joints cut the rock into large irregular blocks. The strike of the schistosity is about N.85°E. and the dip is 45°S. The bedding strikes N.82°W. and the dip varies in short distances, due to minor folding. This outcrop is on the south limb of a larger anticline.

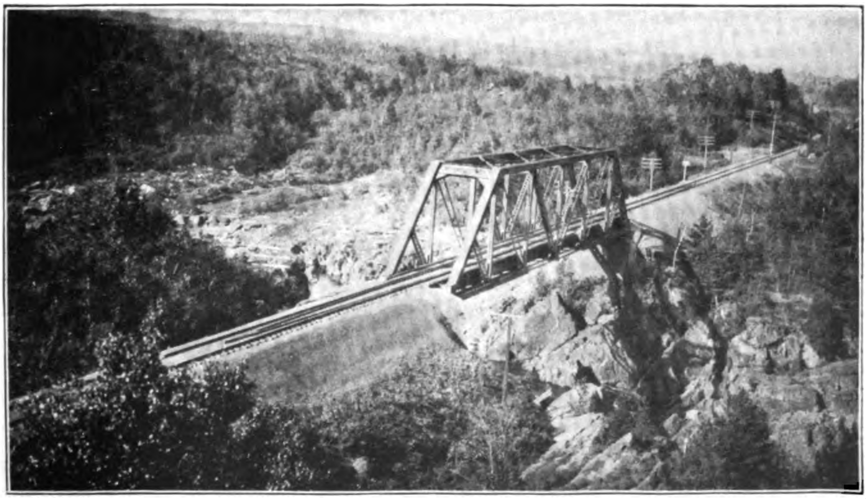
About a mile northeast of the exposure in section 35, near the north quarter corner of section 36, T. 48N., R. 18W., rock is exposed in several small areas. It is mainly light gray, fine-grained graywacke, much weathered and shattered. The beds appear to lie almost flat.

The easternmost rock exposures of the southern belt of outcrops occur in the SW¼ of section 31, T. 48N., R. 17W., along Black Hoof River and west of it, where there are three or four separate outcrops of graywacke and slate. An exposure of graywacke and slate in a low flat ridge is found in the northeastern part of the SW¼ of SW¼ of the section. It lies on a northward facing slope and rises about 10 feet above a swamp to the north of it. The ridge is 600 feet long east and west and 300 feet wide. Small, shattered exposures lie to the east, south and west of the main outcrop for several hundred feet. In the main exposure, layers of light gray, fine-grained graywacke, hard and siliceous, and with poorly developed cleavage, alternate with darker slaty layers having well-developed cleavage. The layers vary from a few inches to several feet thick, the graywacke beds being thicker. The slaty layers show fine mica developed along cleavage planes. Lenses and stringers of quartz occur parallel to the bedding. The rock lies on the crest of a large anticline with small anticlines and synclines on either limb. The axial line of the anticline strikes about east and pitches about 10°E.

About a quarter of a mile to the north of this exposure, in the NW¼ of SW¼ of the section, is a ridge of dark gray slate trending northwest. The ridge rises only a few feet above the surrounding flat, swampy country. It is about 500 feet long and about 200 feet wide. The rock is uniform, dark gray slate with fine mica developed locally along cleavage planes. Thin laminae and specks of limonite lie parallel to the cleavage and also occur as small spots throughout the rock. In the fresher phases pyrite is abundant, indicating that the limonite is derived from pyrite by weathering. The slate forms a synclinal trough that pitches a little south of east at a low angle.



A. OUTCROPS OF SLATE ALONG ST. LOUIS RIVER BELOW THOMSON DAM, CARLTON COUNTY. LOOKING NORTHWESTWARD



B. OUTCROPS OF SLATE AT THE NORTHERN PACIFIC RAILROAD BRIDGE OVER ST. LOUIS RIVER BELOW THOMSON DAM, CARLTON COUNTY. LOOKING SOUTHWESTWARD

UNIV. OF MICH.

West of these two ridges in the western part of the SW¼ of section 31, and extending into the SE¼ of section 36, T. 48N., R. 18W., are small, low, badly broken exposures of dark gray slate. No outcrop showing the attitude of the rock was found.

About a quarter of a mile east of the outcrops described above in the NW¼ of SE¼ of section 31, several small exposures of light gray, medium-grained graywacke are found along Black Hoof River. The rock is hard and siliceous and shows no cleavage.

The next group of exposures northeast of the Atkinson–Park Lake region are those in the vicinity of Otter Creek in sections 16, 17, and 20, T. 48N., R. 17W. Most of these exposures occur along the Northern Pacific Railway which runs northeastward from Atkinson to Carlton. Some are found along Otter Creek.

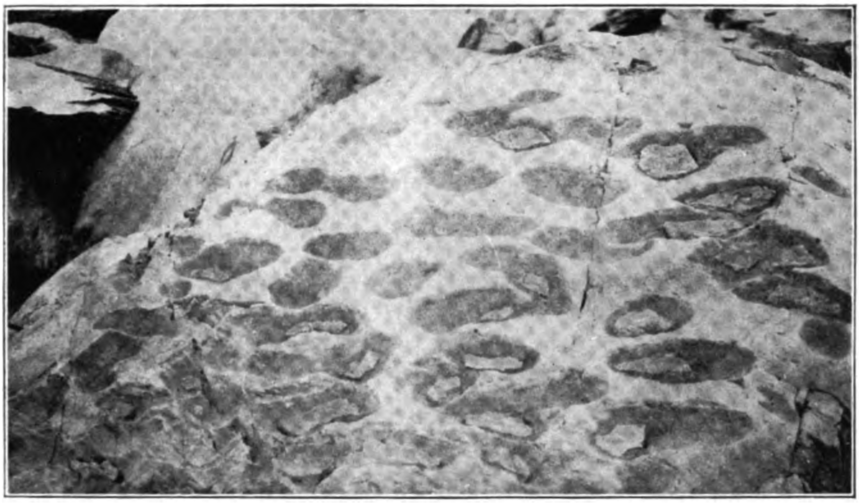
A short distance northeast of the center of the SW¼ of NW¼ of section 20, T. 48N., R. 17W. are two small low ridges of slate and graywacke. The outcrop begins along the northeast-southwest road which runs parallel to the Northern Pacific railway tracks, northeastward from Atkinson, and continues southeastward across the Northern Pacific tracks. It is about 300 feet long and about 40 feet wide. Thin bands of dark gray slate are interlayered with thick beds of lighter gray graywacke. The rock is broken into large blocks by intersecting joints. Quartz, with small crystals of pyrite, occurs in narrow veins and lenses. The bedding strikes about N.85°W. and dips 47°N.

About a fourth of a mile northeast of this outcrop in the east central part of the NE¼ of NW¼ of section 20, several low east-west rock ridges occur along the Northern Pacific tracks and along the highway. They vary in length from 50 to 300 feet and in width from 30 to 100 feet. The rock consists of dark gray slate, some layers of which are very siliceous and have poorly developed cleavage, while other layers are less siliceous and show good cleavage. The layers range in thickness from a fraction of an inch to several inches. Small crystals of calcite and siderite are abundant in the more siliceous layers. In one layer small flattened oval particles of black slate are embedded in the lighter-colored siliceous slate. The rocks lie in a series of small anticlines and synclines, the axial lines of which strike about N.80°E. and pitch from 10° to 20°E.

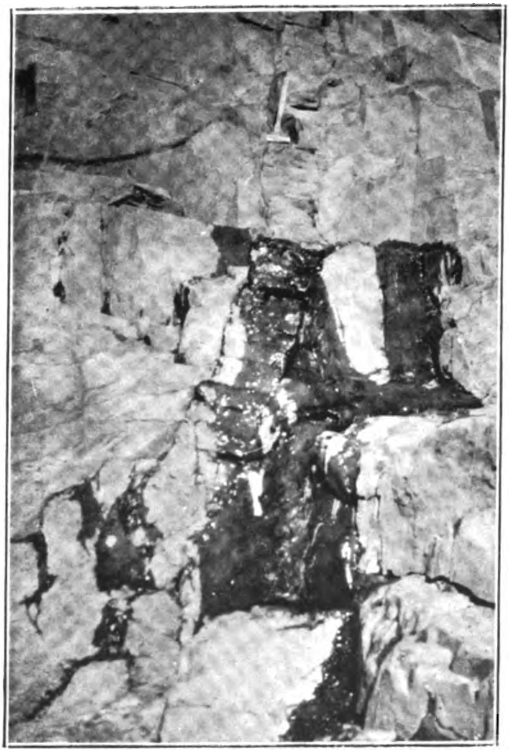
About 200 feet southwest of the Northern Pacific Railway bridge over Otter Creek, in the northeastern part of the SE¼ of SE¼ of section 17, T. 48N., R. 17W., the railway passes through a rock cut for about 110 feet. This cut is through the northwest corner of a high east-west rock ridge about 500 feet long and 175 feet wide which rises about 50 feet above Otter Creek. Layers of slate and schistose graywacke are exposed along the cut, striking N.80°E. and dipping 30°N. The following succession of beds is found. At the bottom, with 5 feet exposed, is a dark gray, fine-grained, siliceous slate. On the cleavage surfaces are seen a few rounded, flat, black particles, probably squeezed slate fragments. Specks of pyrite and some carbonate are disseminated through the rock. Above this layer are 3 feet of uniform, dull, black, dense slate; above that 4 feet of dark gray siliceous slate and schistose graywacke which in places contain pebbles of fine-grained, darker slate, flattened transversely to the cleavage. The pebbles range from a fraction of an inch to several inches in the longer diameter. Alternating thin layers of slate of different coarseness of grain and color are clearly visible in this bed, the coarser layers carrying the slate pebbles. The cleavage cuts transversely across the layers and has fine flakes of mica developed along it. The coarser layers are finely mottled, due to abundant limonite specks, probably derived from the alteration of siderite. The next 5 feet consist of dark greenish phyllite finely mottled with tiny specks of limonite. A few small oval flattened particles of dark slaty material are found on the cleavage faces. Above this bed is a layer of dark gray, coarse-grained, schistose graywacke 3 feet thick. It is similar to the bed below it, but coarser, containing abundant small rounded particles of dark slaty material, as well as numerous grains of quartz. Small specks of limonite and of white carbonate minerals are scattered through the rock. Pyrite is found locally and fine mica is developed along cleavage planes. The cleavage is well developed. The top layer in the cut is a dark gray to black, uniform, fine-grained slate. The thickness could not be determined, but about 15 feet are exposed in the cut. The cleavage strikes about N.87°E. and dips 75°S.

Northeastward from Otter Creek to Carlton a few ridges of slate and graywacke are found both north and south of the Northern Pacific tracks. The ridges trend about east and west and rise from a few feet to 50 feet or more above the surrounding flat region. These ridges have not as yet been examined in detail. To the northeast they connect with the extensive exposures of rock along St. Louis River in the vicinity of Carlton, Thomson, and Cloquet.

In the St. Louis River valley slates and graywacke with a few dikes of dark igneous rock are exposed almost continuously along the river from the center of section 1, T. 48N., R. 16W. on the southeast, to the eastern part of section 15, T. 49N., R. 17W. on the northwest, a distance by river of about 15 miles. These rocks rise as high steep escarpments on both sides of the river for much of the distance and within this gorge are numerous falls and rapids. They also rise as long, narrow, east and west rock ridges, that extend from a few hundred feet to several miles on either side of the river gorge. These ridges are very numerous



A. CALCAREOUS CONCRETIONS WEATHERING OUT OF SLATE AT CARLTON



B. SMALL DIKE OF DIABASE INTRUDING SLATE AT CARLTON

locally. In the region around Carlton and Thomson they cover several square miles and continue southwestward from Carlton for some distance in the direction of Otter Creek.

In the southeastern part of the region the slate and graywacke are associated with younger rocks such as the sandstones, conglomerates, and basic lavas of the Keweenawan. In sections 1 and 2, T. 48N., R. 16W., a coarse quartzose Keweenawan conglomerate lies unconformably on the upturned edges of the slate and graywacke. In the bed of Mission Creek and its tributaries, in sections 30 and 31, T. 49N., R. 15W., north of Fond du Lac, are several exposures of slate north of the overlying Keweenawan sandstone. Outcrops of slate and graywacke also occur along Midway Creek in sections 5 and 6, T. 49N., R. 15W., a short distance west of the border of the lava flows extending northward from Duluth.

The outcrops throughout the St. Louis River valley are made up of alternate layers of slate and graywacke, varying in coarseness of grain and ranging from light gray to black in color. Locally dikes of dark igneous rocks are abundant. The common rocks are fine-grained, dark gray to black slate, some of which is highly siliceous; gray, somewhat micaceous slate with well-developed cleavage, and fine-grained to medium coarse-grained graywacke, some showing cleavage and some being massive bedded and siliceous with little or no schistosity. In some of the coarser beds quartz grains are abundant and a few fragments of slate are locally present. Concretions or nodules of carbonate minerals occur both in the slate and graywacke. They are generally parallel to the bedding and locally they merge into each other, forming continuous bands. In places the longer axes of the concretions are parallel to the cleavage and stand at an angle to the bedding. On weathering they leave pod-like cavities, stained a rusty brown or black. (Plate X A.)

Several sets of intersecting joints cut the rock into polygonal blocks of various sizes. Faulting has taken place along some of the joints, as shown by breccia zones and slickensided surfaces. Thin films of quartz and in places calcite, coat some of the joint planes. Quartz occurs as veins from a fraction of an inch to several feet in width in many parts of the area and also as lenses between slate beds on the crests of smaller folds pinching out along the limbs. Pyrite and siderite are often associated with the quartz and they also occur as small crystals disseminated in the rock.

Dikes of dark igneous rock, varying from a few inches to 60 feet or more wide, cut the slate series in many places. Several are well exposed at the Thomson dam. The rock is mainly a fine-grained, greenish black diabase. At the contact with the slate or graywacke it is extremely fine-grained and dense. Away from the contact it becomes coarser and takes on a marked ophitic texture. The dikes strike, in general, a few degrees east of north and stand vertically. At the contact the metamorphosed sediments have been hardened and their cleavage destroyed, while a new cleavage is developed in them parallel to the contact of the dike. This condition extends out from the dikes on either side for a few inches to several feet. The dikes are more readily broken down by weathering than the slate or graywacke, and are generally found in depressions.

The rocks in the Carlton-Cloquet region lie in a series of low, broad folds, with minor folds and crenulations superimposed on the limbs of the larger folds. The major structure consists of several large, gently eastward pitching anticlines and synclines. The east-west trending rock ridges so characteristic of the area around Carlton, are usually formed along the limbs of folds, one of the slopes being approximately parallel to the dip of the bedding and the other slope cutting across the bedding and being steep and ragged. Occasionally ridges are found which are structurally crests of anticlines or troughs of synclines. The strike of the bedding varies with the position of the bed with reference to the fold, but in general it ranges between N.80°W. and N.80°E. The dip of the beds varies from horizontal to vertical both north and south. The strike of the major cleavage varies a few degrees on either side of east and west and the dip is at varying angles both north and south, but is nearly always steeper than the bedding. The axial lines of the minor folds trend about east and pitch at low angles either eastward or westward.

The northernmost outcrop of slate in east central Minnesota, as described by Spurr,[70] occurs in the vicinity of Brookston in southern St. Louis County. The outcrop is said to be located south of St. Louis River, in NW¼ of SW¼ of section 27, T. 51N., R. 19W. The rock is described as consisting of alternate layers of siliceous slate, fine-grained slate, and sericite schist or slate, the layering being due to the difference in coarseness of the original sediments. The schistosity or cleavage is about at right angles to the bedding. The cleavage strikes about N.70°E. and has a steep dip. The outcrop has not been seen by the writers.

OUTCROPS OF SANDSTONE AND OTHER CLASTIC ROCKS

KEWEENAWAN SANDSTONE AND RELATED ROCKS

Outcrops of pink and red sandstone are abundant in east central Minnesota, occurring at intervals along a belt extending southwestward from the southwestern end of Lake Superior through Carlton, Pine, and Kanabec counties. These rocks have been generally described as belonging to the Lake Superior sandstone, the character and age relations of which have already been discussed. (See pages 13 and 14.)

---

[70] Spurr, J. E., The stratigraphic position of the Thomson slate: *Am. Jour. Sci.*, 3d ser., vol. 48, p. 164, 1894.

The most southwesterly of the sandstone exposures is described by Upham[71] as occurring on Snake River in the NW¼ of section 3, T. 39N., R. 24W., Kanabec County. The sandstone is said to be exposed along the southwest side of the river for a distance of 300 feet with a width of 75 feet. It rises from 5 to 10 feet above the river, in places having a vertical outcrop. It is a coarse-grained sandstone of gray to brown color, showing thin layering and containing local beds of dull red sandstone. Pebbles varying up to several inches in thickness occur scattered through it. Fossils have not been found. The rock has a low dip to the east, 15° being the maximum.

The next sandstone outcrop to the north is one reported as occurring in the southern part of T. 40N., R. 23W.[72] It is mapped as extending along Snake River and is said to consist of interbedded red sandstone and ash-colored clay.

Aside from these two exposures, no sandstone is known along Snake River south of that mentioned on page 43 as occurring in section 23, T. 42N., R. 23W., just south of the big bend in the river. The largest exposure in this locality is found on the west bank of the river and forms a small cliff for a distance of about 300 feet along the stream. It consists of interlayered coarse-grained sandstones of slightly varying texture and color. Most of the rock is light-colored pinkish gray to pink, and massive; but near the base of the cliff a thin layer of dark red shaly sandstone occurs. Locally small pebbles of quartzite and other material are found in some of the layers. The general dip of the beds is 10° to 15°SE. A second outcrop occurs about 500 feet farther downstream on the east bank. This exposure is small and consists of sandstone similar to that described.

The sandstone outcropping along Snake River was all mapped by Upham as "Potsdam" sandstone. Although no fossils were found in it which might aid in determining its position, it was believed to underlie the Upper Cambrian and to be of Lower Cambrian age.

Numerous exposures of sandstone are mentioned by Upham[73] as occurring along Kettle River southward from Willow River in the western part of Pine County, and also along St. Croix River in the southern part of Pine County. Most of these outcrops were designated as "Hinckley" sandstone, but one or two were mapped as "Potsdam" sandstone. The term "Hinckley" sandstone was applied by Winchell, Upham, and others of the Geological and Natural History Survey of Minnesota to sandstone beds which are not definitely a part of the Upper Cambrian series, but which are stratigraphically above the so-called "Potsdam" sandstone. In some reports it is considered as the lowest member of the "St. Croix" and in other reports as the uppermost member of the "Potsdam." The "St. Croix" sandstone of the early reports embraced the lower portion of the Upper Cambrian.

---

[71] Upham, Warren, The geology of Mille Lacs and Kanabec counties: *Geol. and Nat. Hist. Survey of Minn., Geol. of Minn.*, vol. 2, 1882-1885, pp. 621-622.

[72] Upham, W., *op. cit.*

[73] Upham, Warren, The geology of Pine County, *op. cit.*, pp. 637-642.

Exposures of the same sandstone are mapped by Winchell as occurring along the upper part of Kettle River west of Moose Lake in Carlton County, while the abundant exposures of sandstone and conglomerate occurring along St. Louis River west of Fond du Lac in southern St. Louis County are designated by Winchell as Puckwunge conglomerate and "Western" sandstone.[74] All of these beds are believed to be stratigraphically below the lowest fossiliferous "St. Croix" beds which are found along St. Croix River above and below Taylor's Falls, the Puckwunge conglomerate, which was classed as "Potsdam," being the lowest.

The sandstone which is found in numerous exposures along Kettle River in Pine County is described by Upham as occurring in bluffs along the river banks, and also forming the river bed in many places and producing rapids. For a long distance north and south of Sandstone the river flows through a great gorge in which sandstone is exposed both along the river banks and along the tops of bluffs 75 to 100 feet above the river. The rock is mostly fine-grained sandstone, but coarse-grained phases occur which, however, are rarely conglomeratic. It generally crumbles easily, and as a rule varies in color from buff to gray, though red and brown phases occur also. The beds lie flat or dip in various directions at low angles.[75]

Exposures of sandstone are found along St. Croix River in the southeastern part of Pine County, above and below the mouth of Snake River, as well as a short distance above the mouth of Kettle River. The exposures near the mouth of Snake River are mapped as "Hinckley" sandstone, and are said to be of friable gray and white sandstone with locally beds of conglomerate and of red, green, and yellow shale. The rocks are distinctly bedded, being horizontal, or having a slight inclination to the south. They are believed to belong to a higher stratigraphical horizon than the sandstone found along Kettle River. The outcrops north of the mouth of Kettle River are designated as "Potsdam," and are said to consist of red sandstone with underlying conglomerate.

The sedimentary rocks found along St. Louis River in Carlton and St. Louis counties are divided by Winchell[76] into two stratigraphic horizons. The lower beds are designated as Puckwunge conglomerate, and are believed to be of Lower Cambrian age. Exposures occur along St. Louis River and north of it at various points. The formation is said to be about 100 feet thick, and to grade from coarse conglomerate at the base upward into white sandstone and light-colored shale, and then into red shale which is overlain by rocks of eruptive origin.[77] The latter are designated as the "Manitou" eruptives of late Keweenawan age, and are said to stratigraphically underlie the so-called "Western" sandstone. This rock consists mainly of red sandstone and conglomerate which grade upward into lighter-colored sandstone. Its upper portion is believed to represent the so-called "Hinckley" sandstone. In the recent work by Thwaites already referred to (see pages 13 and 29), the sandstones along St. Louis River have all been placed in the Bayfield group of the upper Keweenawan.

---

[74] Winchell, N. H., The geology of southern St. Louis County: *Geol. and Nat. Hist. Survey of Minn., Geol. of Minn.*, vol. 4, 1896-98, Pl. 66.

Winchell, N. H., The geology of Carlton County, *op. cit.*, pp. 13-16.

[75] Upham, W., *op. cit.*

Besides the sandstone outcrops mentioned by Winchell and Upham, a number of scattered occurrences of sandstone in southern Carlton and northern and western Pine counties are mapped by Hall.[78] No descriptions of the localities, however, are given.

The relative stratigraphic positions of the various beds of sandstone occurring in St. Louis, Carlton, Pine, and Kanabec counties is unknown. If the fossiliferous Upper Cambrian series rests conformably upon the red clastic series in southern Minnesota, as seems probable, and if the latter is supposed to be equivalent to the Keweenawan pink and red sandstone of east central and northern Minnesota, which in earlier reports has been called "Hinckley" sandstone, "Western" sandstone, "Lake Superior" sandstone, etc., then the rocks exposed in the southern part of Pine County can probably be regarded as showing the transition from the lower part of the Upper Cambrian into the upper part of the Keweenawan sandstone (red clastic series?). The question as to whether the so-called "Hinckley" sandstone belongs to the Upper Cambrian series or to the Keweenawan can not yet be answered, nor, as has been mentioned before, do we know whether the sandstone southwest of Lake Superior is Cambrian or Keweenawan in age, although the latter view seems to be the more probable.

CRETACEOUS SEDIMENTS

Besides the outcrops of the older sandstones just described in the eastern portion of the region under consideration, there are a number of scattered outcrops of slightly consolidated sediments occurring in the southwestern portion of the region. These, because of their softness,

---

[76] Winchell, N. H., The geology of Carlton County, *op. cit.*

[77] Winchell, N. H., *op. cit.*, p. 13.

[78] Hall, C. W., Keewatin area of eastern and central Minnesota: *Bull. Geol. Soc. Amer.*, vol. 12, Pl. 29, 1901.

do not yield extensive exposures, but locally, as along Mississippi River and in the region to the west, scattered outcrops show their presence. Mosasaur teeth and other fossils have been found in them in places and indicate that they are of Cretaceous age.

Only one of these outcrops was examined by the writers, this occurring on the west bank of Mississippi River, just above the mouth of Two Rivers in the southern part of Morrison County. Much of the material at this locality consists of unconsolidated or slightly consolidated gray clay locally yellow or brown iron-stained. Some beds of fairly compact shale and siliceous shale occur, however. These are light gray to dark gray in color and locally greenish. Very commonly they are impregnated with limonite so that they have a yellow to dark brown color. Much of the material has curious little concretionary pellets scattered through it. In places these are so abundant as to make up most of the rocks, while elsewhere they are entirely lacking. Where the rock is iron-stained the pellets are dark brown. Elsewhere they are green or gray.

Other occurrences of Cretaceous sediments described by Upham[79] are in the southern part of Stearns County near Torah (Richmond). Three miles north of Torah (Richmond) in a ditch dug for drainage, yellow and blue clay were encountered with three seams of lignite from 1 to 6 inches thick. Locally pyrite was found in the blue clay. Southwest of Torah (Richmond) along Sauk River, considerable prospecting is said to have been done for lignite. Several shafts were sunk ranging in depth up to 125 feet. Most of the material encountered consisted of blue, white, and yellow clays in which were local beds of gray to black shale and seams of lignite several inches thick. Fossil fragments of mollusks and fishes were found in some of the shale beds. In places, crystals of selenite were found in the blue clay near the lignite seams. Granite was found to underlie the Cretaceous sediments.

THE CUYUNA IRON-ORE DISTRICT

LOCATION OF THE DISTRICT

The Cuyuna iron-ore district is located in the central part of Minnesota, trending southwesterly from the center of Aitkin County through Crow Wing and Morrison counties, into Todd County. The most important part of the iron-bearing belt is in Crow Wing County. This part has a course approximately parallel to Mississippi River and lies southeast of it. In the southwestern part of the district, between Brainerd and Little Falls, Mississippi River, changing its course from southwest to south, crosses the ore-bearing belt. Southwest of this point the ore-bearing belt continues in the same general direction through Morrison County and into Todd County, beyond which it is not known. Northeastward, the iron-bearing belt runs from Crow Wing County into Aitkin County and disappears beyond Rice River.

---

[79] Upham, Warren, The geology of Stearns County: *Geol. and Nat. Hist. Survey of Minn., Geol. of Minn.*, vol. 2, 1882-1885, pp. 459-461.

The district has a length northeast and southwest of about 65 miles, and ranges in width from a mile or two to as much as 12 miles, not including the Emily area in northern Crow Wing County where iron-bearing rocks have been found in scattered localities. The region presented for exploration amounts to approximately 40,000 acres.[80] Much of this area is under cultivation, farms being scattered throughout. Forested and brush lands also occupy large areas, and locally swamps occur along the iron-bearing belts.

Although Mississippi River flows through the district, the drainage is very imperfect. Lakes are very abundant throughout the region. The largest of these is Mille Lacs Lake, 14 miles wide by 16 miles long, situated about 14 miles southeast of Deerwood. The lakes are especially numerous in the eastern part of the district, where extensive moraines occur, and decrease in number toward the southwest where outwash plains predominate over moraines.

The valley of Mississippi River is narrow and in general is not very deep, although locally as at Brainerd there is a distinct gorge. Its only large branch in the region under discussion is Crow Wing River, which empties into it from the west about 10 miles below Brainerd. Small side streams, however, are abundant, but these, as a rule, have worn their valleys only short distances back from the Mississippi.

The topography of the district is predominantly morainic. Over large areas it is hummocky, numerous small hills being interspersed with swampy areas and lakes. In other places there are extensive outwash plains and the surface is level or gently undulating. The greatest difference in elevation is about 200 feet. The elevations vary from 1,150 feet above sea level, which is approximately the elevation of Mississippi River in the western part of the district, to about 1,350 feet, which is the elevation of some of the higher hills in the eastern part of the district. The highest point in the region adjacent to the Cuyuna district is Warren Hill, just west of Mille Lacs Lake, the summit of which is 1,450 feet above sea level. Mille Lacs Lake has an elevation of 1,249 feet.

The principal towns along the ore-bearing belt from northeast to southwest are Kimberly and Aitkin in Aitkin County; Deerwood, Cuyuna, Crosby, Ironton, Manganese, Trommald (formerly Iron Mountain),

---

[80] Zapffe, Carl, The Cuyuna iron-ore district of Minnesota: *Supplement to Brainerd Tribune*, July 1, 1910.

Riverton, Woodrow, Brainerd, and Barrows in Crow Wing County; and Randall in Morrison County. Of these towns, all those located in Crow Wing County except Deerwood and Brainerd were built since the beginning of the development of the iron mines. The oldest of these, Cuyuna, is about nine years old. The largest city in the district is Brainerd, which has a population of about 8,000 and which at one time was one of the lumber centers of northern Minnesota. It was also here that the general offices of the Northern Pacific Railway were located before they were moved to St. Paul. At the present time Brainerd is the center of a fairly prosperous and constantly growing farming community. Of the other cities on the range, Aitkin also is well established and is independent of the iron-mining industry. Kimberly, Deerwood, and Randall are smaller towns, built before iron ore was discovered in the region. All the other towns mentioned are more or less dependent on the iron-mining industry to which they owe their establishment.

Two railroads serve the Cuyuna district, the Duluth-Brainerd branch of the Northern Pacific Railroad, built in 1870, and the Cuyuna Range branch of the Minneapolis, St. Paul, and Sault Ste. Marie Railroad, built in 1910. The former runs from Duluth and Superior westward through Carlton, Aitkin, Deerwood, and Brainerd, to Staples where it joins the main line of the Northern Pacific to the West Coast. In its passage through the iron-ore district, it runs approximately parallel to the ore-bearing belts. A branch line of the Northern Pacific also runs along the east side of Mississippi River between Brainerd and Little Falls connecting at the latter point with the main line to Minneapolis and St. Paul. A number of small branches run to various mines in the iron-ore district.

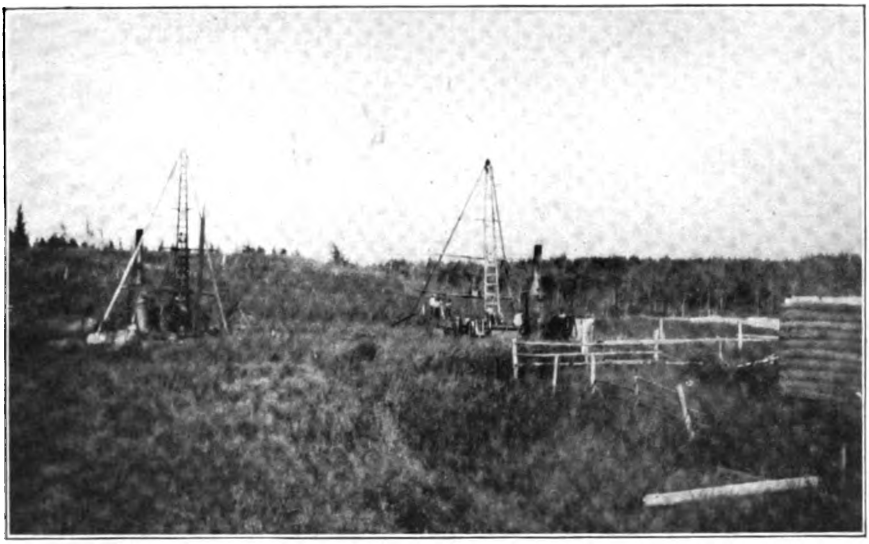
The Cuyuna Range branch of the Minneapolis, St. Paul, and Sault Ste. Marie Railroad leaves the Duluth-Winnipeg branch of this road at Lawler and runs westward through Aitkin to Iron Hub. Here it divides, a northern branch going to Manganese and a southern branch through Cuyuna, Crosby, and Ironton, to Riverton. Various mines are connected with the main lines by branch railways.

HISTORY OF THE DISTRICT

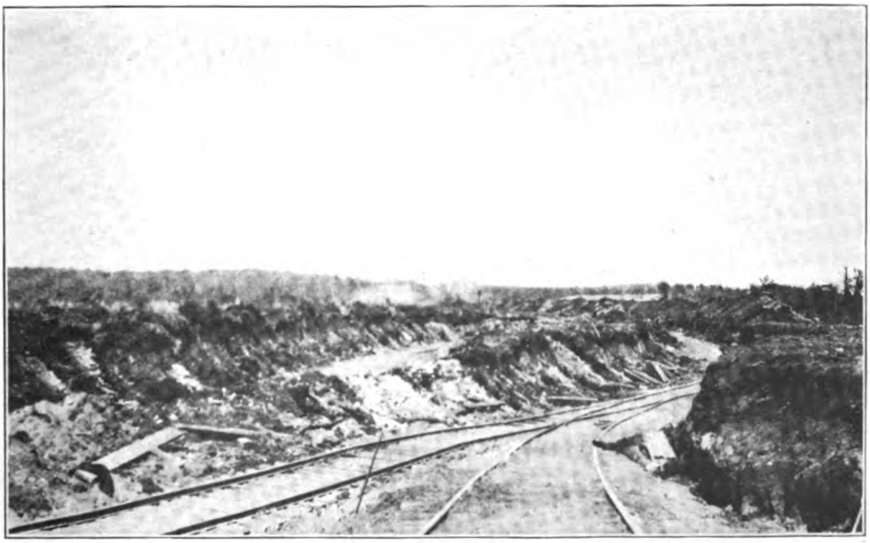
That iron ore might be found in east central Minnesota was suspected long before its actual discovery. It is said that when the Northern Pacific Railway surveys for the present road were being made previous to 1870, through what is now the Cuyuna district, indications of the presence of iron ore were found,[81] due probably to compass disturbances being noted. Mention of variations in the direction of the compass needle

---

[81] Kellogg, L. O., Notes on the Cuyuna range, I and II: *Eng. and Min. Jour.*, vol. 96, pp. 1199-1203, Dec. 27, 1913; vol. 97, pp. 7-10, Jan. 3, 1914.



A. EXPLORATION BY DRILLING IN THE CUYUNA DISTRICT



B. STARTING EXCAVATION WITH STEAM SHOVEL AT THE MAHNOMEN OPEN-PIT MINE, NEAR IRONTON

PHOTO BY CARL ZAPPFE

in parts of Crow Wing County are said to be found also in the notes of the government land surveyors made in the 70's, at which time the Marquette Range of northern Michigan was the only iron-ore producing district in the Lake Superior region.

It was about 1890 when the first magnetic surveys were made in east central Minnesota for the purpose of locating areas of abnormal magnetic attraction, such as are assumed to indicate the presence of iron ore. From this time until the actual discovery of the existence of iron-bearing formation in the Cuyuna district, during the summer and fall of 1904, magnetic surveys were made at intervals in different parts of the region. Some time elapsed, however, before the regularity and extensiveness of the magnetic variations were realized, and after this, systematic exploration work progressed rapidly. Most of the early magnetic work was done by Mr. Cuyler Adams to whom belongs a large share of the credit of discovering and developing the range. It was Mr. Adams also who started the first drilling operations on the range; in fact, it was not until he had encountered iron-bearing formation with a churn drill that the existence of the new iron range became common knowledge.

Mr. Adams first became interested in the region now known as the Cuyuna district early in the 90's, when the Mesabi district was still a wilderness.[82] His attention had been drawn to the area by the fact that he noted magnetic variations on certain lands which he had purchased, and at various times he made magnetic surveys with dial compass and dip needle in attempts to locate lines of maximum magnetic attraction.[83] In this he was successful, and eventually two such lines were located, both having northeast-southwest trends. One of these lines was 12 to 15 miles long and was located south of Deerwood, in general running parallel to and south of the Northern Pacific Railway. It extended from the west line of section 10, T. 46N., R. 28W., southwesterly across the corners of T. 46N., R. 39W., and T. 45N., R. 29W., to the center of the west line of section 29, T. 45N., R. 30W. The other line was found about 7 miles north of Deerwood, running in a northeast-southwest direction across section 30, T. 47N., R. 28W. south of Rabbit Lake. Both lines seemed to feather out at the ends.

Drilling was begun in the district in May, 1903,[84] the first holes being put down in the SW¼ of the SE¼ of section 16, T. 46N., R. 28W., near the northeast end of the southern line of attraction, while later holes were put down in sections 21, 20, and 10, T. 46N., R. 28W., also on the southern line of attraction. Exploration work was begun in section 30, T. 47N., R. 28W., south of Rabbit Lake on the northern line of attraction, in July, 1904. Five drills were active throughout the summer of 1904, and by October, 1904, twenty-two holes, more than half of which encountered iron-bearing formation or lean iron ore, had been drilled, and the information gained was first given to the public. When the information began to spread, much interest and excitement was created, even though ore in commercial quantity had not yet been found.

---

[82] Thomas, Kirby, A new promising Lake Superior iron district: *Min. Wld.*, vol. 21, pp. 446-448, Nov. 5, 1904.

[83] Adams, Cuyler, Personal correspondence.

[84] Thomas, Kirby, *op. cit.*

Besides this drilling in the central part of the district, it is stated that drilling was done also during the summer of 1904 in the Dam Lake region about three miles south of Kimberly.[85]

Magnetic exploration work progressed very rapidly after the discovery of iron-bearing formation, and soon the district in which abnormal magnetic attractions were found to occur was greatly enlarged by extensions to the northeast and southwest. Various mining companies from the other iron ranges took options on favorably located properties and started exploration work. Among the first of these to come into the district was the Oliver Mining Company of the United States Steel Corporation, which took options on large tracts of land and started drilling operations. After considerable drilling and exploration, however, this company withdrew from the district and has not since then been identified with any of the Cuyuna range operations. Other companies that came into the district from other ranges are Pickands, Mather and Company, Rogers-Brown Ore Company, Tod-Stambaugh Company, M. A. Hanna and Company, Inland Steel Company, Ogelbay, Norton and Company, and Jones and Laughlin Steel Company. Some of these companies have become permanently identified with the district, while others withdrew after preliminary exploration work.

Not long after the discovery of the existence of iron-bearing formation in the Cuyuna district, the possible connection between the iron-bearing formation of the western end of the Mesabi district and that of the Cuyuna district became a subject of considerable interest, and soon drilling was started in the region southwest and south of Grand Rapids and north and northwest of Aitkin. This drilling has continued to the present time, and ore has been found locally in this region.

The first attempt at underground work in the Cuyuna district was made by the Hobart Iron Company of Pickands, Mather and Company, which sunk a 120-foot shaft with several hundred feet of cross cuts in the SW¼ of the SE¼ of section 8, T. 45N., R. 29W. This work was done in 1905 and the early part of 1906, but the operation was abandoned after some months.

---

[85] Thomas, Kirby, Notes on the geology of a new iron ore district in Minnesota: *Mines and Minerals*, vol. 25, p. 27, August, 1905.

The first permanent mining shaft in the Cuyuna district was sunk by Rogers-Brown Ore Company. During the summer of 1907 this company started drilling on lands on which they had secured options in sections 29 and 30, T. 47N., R. 28W.[86] south of Rabbit Lake. Some of these lands had been previously drilled by other companies, including the Oliver Mining Company, the latter having secured an option on the properties, but having released them because the results of exploration were considered unsatisfactory. The indications of the presence of ore, as shown by the Rogers-Brown Ore Company exploration work, appeared so favorable, that this company took a lease on the properties and started sinking its shaft, which has developed into the present Kennedy mine. The Oliver Mining Company had already attempted sinking a shaft on the tract, but this had caved in at a depth of 25 feet. Previous to starting their permanent shaft, the Rogers-Brown Ore Company, therefore, sunk an exploration shaft less than 100 feet south of the old Oliver Mining Company's shaft in order to test the surface. This was put down to a depth of 50 feet, and as no great difficulty was encountered, the permanent shaft was started near the southeast corner of lot 5 of section 30, T. 47N., R. 28W., about half a mile northeast of Cuyuna. The shaft was begun as a 10 by 16 foot lath shaft, but considerable quicksand was encountered, and it was changed to a drop shaft, which after great difficulty and nearly a year of uncertainty was finally ledged at a depth of 112 feet in October, 1908.[87]

In the meantime exploratory drill work had been carried on throughout the region so that the district had been greatly extended both to the northeast and southwest. By 1909, 2,000 holes had been drilled, and iron-bearing rocks with associated ore had been proved to exist in two parallel northeast-southwest belts, one north of the Northern Pacific Railway, known as the north range, and the other south of the railway, known as the south range.[88] In the south range iron-bearing formation had been shown to occur as far northeast as Rice River, T. 48N., R. 26W., and southwest as far as Mississippi River, T. 43N., R. 32W., a distance of about fifty miles. In the north range, iron-bearing formation had been found at various localities in T. 47N., R. 28W., T. 47N., R. 29W., and T. 46N., R. 29W. In addition to this, iron-bearing formation had been found also west of Mississippi River in T. 133N., R. 32W., southwest of Staples.[89] However, exploration work was actively continued, and during the fall of 1910 forty drills were at work in various parts of the range.

---

[86] Woodbridge, D. E., Iron ore in Crow Wing County, Minnesota: *Eng. and Min. Jour.*, vol. 84, pp. 775-776, Oct. 26, 1907.

[87] Anon., A difficult shaft sinking operation at Deerwood, Minnesota: *Iron Tr. Rev.*, vol. 43, pp. 772-774, Nov. 5, 1908.

[88] Adams, F. S., The iron formation of the Cuyuna Range: *Econ. Geology*, vol. 5, pp. 729-740, 1910; vol. 6, pp. 60-70, 156-180, 1911.

[89] Adams, F. S., *op. cit.*

When the iron-bearing rocks in the district were first discovered, Brainerd, Deerwood, and Aitkin were the only towns of importance in the region, and Deerwood was the only town located in the area where the first important deposits of iron ore were discovered. It was not long, however, before new townsites were established and Cuyuna, Crosby, and Ironton became active, growing towns. Cuyuna was settled in 1908, Crosby was platted in 1909 and settled in 1910, while Ironton was established in 1910. Later the towns of Riverton, Manganese, Woodrow, Barrows, and, more recently, Trommald were settled.

It was not long after the completion of the Kennedy shaft to bed rock, that the construction work on the Minneapolis, St. Paul, and Sault Ste. Marie Railroad branch line into the Cuyuna range was started and by December, 1910, it had reached the town of Cuyuna near the Kennedy mine, and the grading had been completed into Crosby and Ironton.[90] A spur had also been constructed to the Kennedy mine, where the shaft had been sunk to the lowest level (262 feet) and where a stock pile of 45,000 to 50,000 tons of ore was awaiting shipment. The first trainload of ore from the Cuyuna range was shipped over this road from the Kennedy mine in May, 1911.

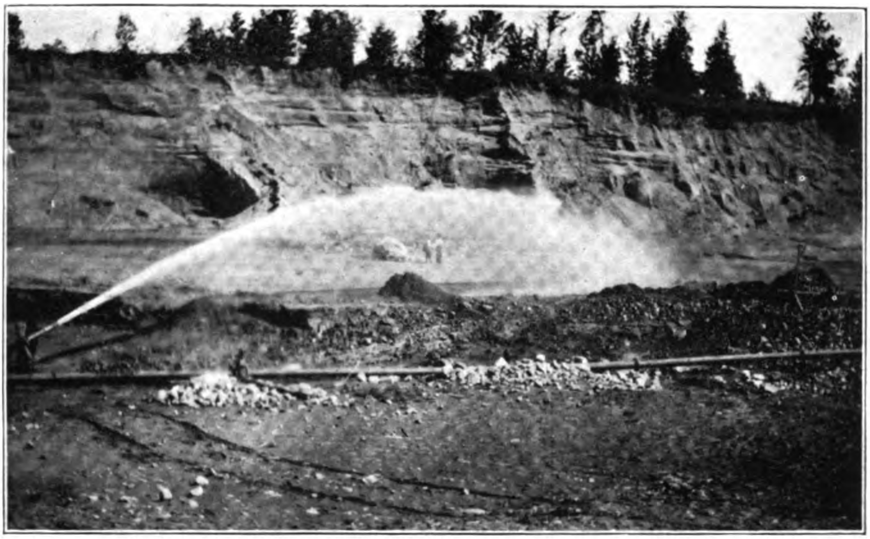
Meanwhile other shafts were being sunk in the north range, and in 1912 the Armour No. 1 and Armour No. 2 mines near Ironton, and the Thompson mine near Crosby, made their initial shipments, increasing the list of producers to four.

The Armour No. 1 mine was opened by the Iroquois Iron Company, which sank a circular concrete shaft south of the ore body during 1910 and 1911. During 1912 and 1913, 159,859 tons of ore were produced from this mine, but in July, 1913, all operations ceased.[91] The property remained idle during 1914, but in January, 1915, the lease of the Iroquois Company was assigned to the Inland Steel Company, who decided to strip the western part of the ore body. Stripping operations were commenced in the spring of 1915 and were continued during the summer, remarkably rapid progress being made. A total of about 800,000 cubic yards of overburden was removed, much of which was taken through the Pennington open pit with which the Armour No. 1 pit is directly connected. Mining operations in the open pit began in August, 1915, and 79,773 tons of ore were shipped before the end of the year. During the season of 1916, the Armour No. 1 mine was steadily operated.

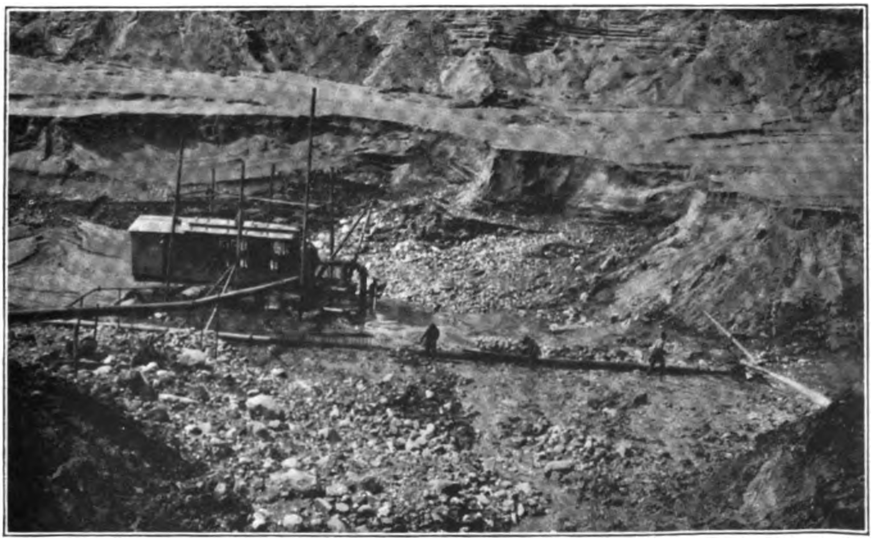
---

[90] Anon., The Cuyuna range, Minnesota: *Eng. and Min. Jour.*, vol. 90, p. 1214, Dec. 17, 1910.

[91] Anon., Armour mines on Cuyuna range: *Iron Tr. Rev.*, vol. 57, p. 1223, Dec. 23, 1915.



A. REMOVING OVERBURDEN BY HYDRAULIC METHOD AT THE ROWE MINE, NEAR RIVERTON. SHOWS STREAM OF WATER ISSUING FROM GIANT NOZZLE WASHING DOWN SAND AND CLAY



B. REMOVING OVERBURDEN BY HYDRAULIC METHOD AT THE HILLCREST MINE, NEAR IRONTON. SHOWS GIANT NOZZLE, CENTRIFUGAL PUMP, AND DISCHARGE PIPE
PHOTO BY CARL ZAPPFE

UNIV. OF MICH.

The Armour No. 2 mine was leased and drilled by the Iroquois Iron Company.[92] Exceptionally good ore is said to have been shown up in the drilling, and it was soon discontinued and a concrete shaft was sunk during 1910 and 1911. Mining was started in 1912, and 524,825 tons of ore were shipped during the seasons of 1912, 1913, and 1914, by the Rogers-Brown Ore Company, which operated the property. In January, 1915, the lease was assigned, together with that on the Armour No. 1 property, to the Inland Steel Company, which shipped 333,856 tons of ore from this mine during 1915. The Armour No. 2 mine has been in steady operation since it was first started, and some of the best ore shipped from the district has come from this mine.

The Thompson mine was started as an underground mine by the Inland Steel Company in 1911. A shaft was sunk between two ore bodies, one on the north and one on the south, and small quantities of ore were shipped during 1912 and 1913. It was then decided to strip the south ore body, and mine the upper part of it by open pit methods. The underground workings were closed in June, 1913,[93] and stripping operations were in progress during the latter part of 1913 and the early part of 1914, the first ore being shipped from the open pit during the summer of 1914. Since then the Thompson mine has been operated steadily. In the fall of 1916 the steam shovels were removed from the pit and milling was inaugurated. At about the same time stripping operations were started on the north ore body and continued during the spring of 1917.

In 1913 five new mines joined the ranks of producing mines. They are the Pennington, Ironton, and Cuyuna–Mille Lacs mines near Ironton, the Iron Mountain (now Algoma) mine near Manganese, and the Barrows mine near Barrows. These mines, with the exception of the Barrows mine, are located on the north range, and two of them, the Cuyuna–Mille Lacs and Iron Mountain mines, are manganiferous iron-ore mines. The Barrows mine is located in the western part of the south range.

The Pennington mine was the first open-pit mine in the Cuyuna district. Excavation was started in January, 1913, and before the end of the year 1,500,000 cubic yards of overburden had been removed and 101,136 tons of ore had been mined.[94] The first carload of ore was shipped August 2, 1913, and shipping continued until the close of lake navigation, about the middle of November. During 1914 the Pennington mine was idle, but shipments recommenced in August, 1915, after the completion of the Armour No. 1 open pit, and were continued during 1916.

---

[92] *Op. cit.*, pp. 1223-1224.

[93] Swanson, August, Annual report of Inspector of Mines, Crow Wing County, Minn., Year ending June 30, 1914, p. 8.

[94] Woodbridge, D. E., Changes and outlook in the lake iron-ore trade: *Iron Age*, vol. 93, pp. 15-18, Jan. 1, 1914.

Anon., The Dean-Itasca and Pennington mines: *Iron. Tr. Rev.*, vol. 57, pp. 1140-1141, Dec. 9, 1915.

The Ironton and Cuyuna-Mille Lacs mines both made small initial shipments in 1913. The Ironton mine is located in the northern part of the village of Ironton on the southwest extension of the Armour No. 2 ore body. It was opened in 1912,[95] and 49,150 tons of ore were shipped during 1913 and 1914. In 1915 the mine was idle and recommenced operations only during the latter part of the season of 1916.

The Cuyuna-Mille Lacs and Iron Mountain mines were the first shippers of manganiferous iron ore in the Cuyuna district. The Cuyuna-Mille Lacs mine is situated just south of Menomin Lake about a mile northwest of Ironton. The shaft was started in October, 1911, and reached bed rock after penetrating about 50 feet of surface drift. In 1913, 27,300 tons of ore were shipped, and shipments have continued to the present time. Until 1916 the Cuyuna-Mille Lacs mine was the only important shipper of manganiferous iron ore in the district, only small shipments being made from the Iron Mountain mine and from one or two of the iron-ore mines. Ore, ranging from about 10 per cent to 30 per cent in manganese,[96] and between 35 and 40 per cent in iron has been shipped from the Cuyuna-Mille Lacs mine, several grades with different manganese and iron content being produced. At present the lower grade ores are being produced in larger quantities.

The Iron Mountain mine, located about half a mile south of Manganese, was opened by the Iron Mountain Mining Company. The first shaft was sunk during 1911 and 1912, but was closed down and a second shaft was started in May, 1913.[97] The first ore was shipped in 1913, consisting of a few carloads used for experimental purposes.[98] The mine was idle in 1914, but operations were recommenced in 1915, 8,600 tons of ore being shipped during the season. In the winter of 1916 the Iron Mountain mine was taken over by the Hoch Mining Company and renamed the Hoch mine. A large tonnage was mined and shipped during the season of 1916. At the present time (summer 1917) the mine is being operated by the Algoma Mining Company and is known as the Algoma mine.

The Barrows mine, located 4 miles southwest of Brainerd, was the first of the south range mines to join the list of producers. It was

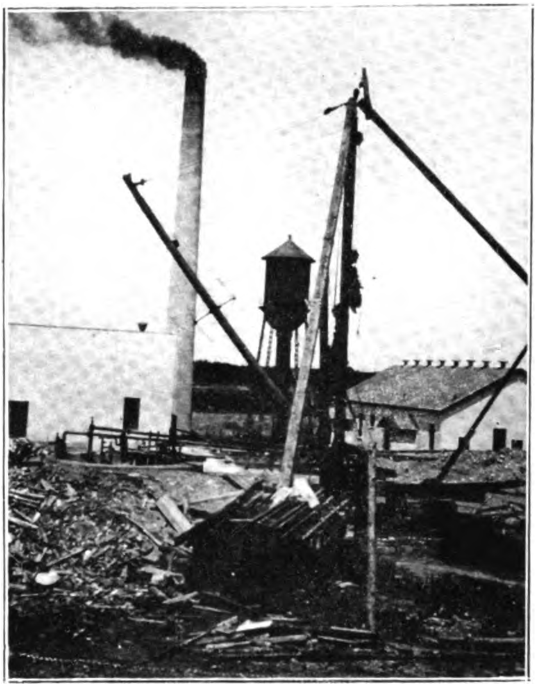
---

[95] Swanson, August, Annual report of Inspector of Mines, Crow Wing County, Minnesota. Year ending June 30, 1914, p. 11.

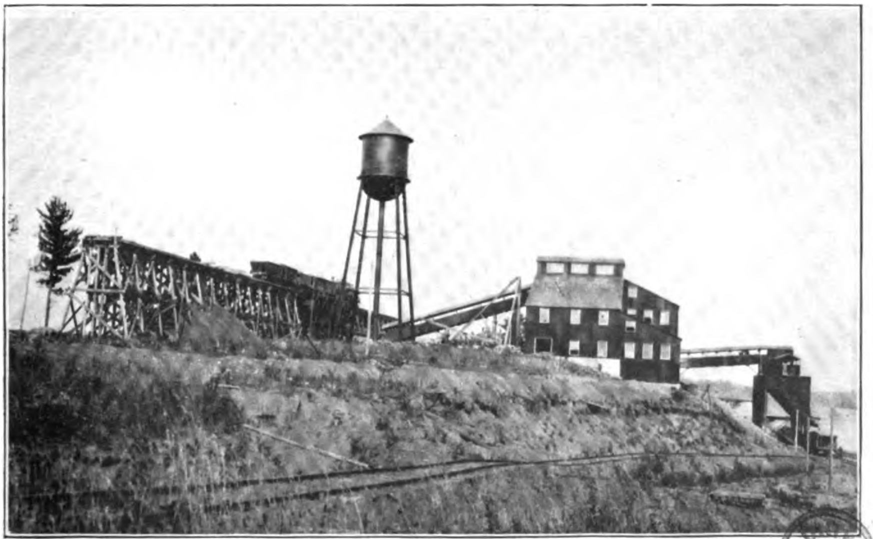
[96] Zapffe, Carl, Matters of interest to operators regarding the Cuyuna district: *Proc. Lake Sup. Min. Inst.*, vol. 20, pp. 196 et seq., Sept. meeting, 1915.

[97] Swanson, August, Annual report of Inspector of Mines, Crow Wing County, Minnesota. Year ending June 30, 1913, p. 11.

[98] Zapffe, Carl, *op. cit.*, p. 197.



A. SINKING A CONCRETE SHAFT AT THE CROFT MINE, NEAR CROSBY
PHOTO BY CARL ZAPPFE



B. IRON-ORE CONCENTRATING PLANT AT THE ROWE MINE, NEAR RIVERTON
PHOTO BY CARL ZAPPFE

UNIV. OF MICH.

soon followed, however, by the Adams mine and more recently by the Wilcox and Brainerd-Cuyuna mines.

At the Barrows mine considerable difficulty was encountered in shaft sinking on account of bad ground. A test shaft was sunk during 1911 to a depth of 80 feet, and the conditions encountered were so serious that the second shaft was started as a timber drop shaft. This was abandoned after reaching a depth of more than 50 feet. A third shaft, also a timber drop shaft, was started early in 1912 and was finally ledged. The Barrows mine was operated by the Virginia Ore Mining Company, of M. A. Hanna and Company, the first ore being shipped from the mine in 1913. Shipments continued until the summer of 1914 when the lease was abandoned and the mine ceased operating. The Barrows mine is owned by the Brainerd Mining Company.

During the shipping season of 1914 only two new mines were added to the producing list, viz., the Rowe mine, near Riverton, on the north range and the Adams mine, 3 miles southwest of Deerwood, on the south range. Several new shafts, however, were started during the year, including the Sultana shaft about a mile northwest of Ironton, the Croft shaft near Crosby, the Wilcox shaft near Woodrow, and the Rowley shaft half a mile south of Barrows.

The Rowe open-pit mine of the Pittsburgh Steel Ore Company was excavated during 1913 and 1914, the first ore being shipped in the autumn of 1914. Sluicing and hydraulic stripping were successfully applied in the removal of the overburden which covered the ore, this being the first instance of such methods being employed in the removal of overburden in the Lake Superior district.[99] The operations were begun in August, 1913, and for a short time the sluicing method was used. The location is near the shore of Little Rabbit Lake, and a hill rising to an elevation of 50 feet above the level of the lake covered the ore body. Water was therefore pumped from the lake up to the hill and turned loose, the returning stream carrying a full burden of material down to the lake. This was continued until the slope became too low for the effective removal of material. A hydraulic giant and a centrifugal sand pump were then installed. The stream from the hydraulic giant undercut the banks of sand and clay, and the material was washed by the water down to a sump where it was picked up through suction by the sand pump and discharged through a 12-inch pipe into the lake. The stripping operations continued into the summer of 1914, a total of about 1,581,000 cubic yards of earth being removed, of which 81,000 cubic yards were removed by the preliminary sluicing. The final clearing up of boulders and other material not removed by hydraulicking was done with steam shovels.

---

[99] Kellogg, L. O., Stripping with the hydraulic giant: *Eng. and Min. Jour.*, vol. 97, pp. 166-167, Jan. 17, 1914.

McAuliffe, P. J., Stripping a mine by hydraulic methods: *Coal Age*, vol. 5, pp. 568-569, Apr. 4, 1914.

McCarty, E. P., Hydraulic stripping at Rowe and Hillcrest mines on the Cuyuna Range, Minn.: *Lake Sup. Min. Inst.*, Sept. meeting, 1915. See also *Iron Tr. Rev.*, vol. 58, pp. 136-139, Jan. 13, 1916.

During 1914, 80,000 tons of ore were shipped from the Rowe mine. But it was found that in many parts of the ore body the "direct-shipping" ore was irregularly mixed with low-grade material which could not be shipped profitably without concentration. Concentration tests were made on this material during the following winter and during the spring and summer of 1915, a concentrating plant was erected. No ore was mined during this time, but in August, 1915, upon the completion of the concentrating plant, operations recommenced and 143,163 tons were shipped before the season closed. A large part of this tonnage consisted of concentrates.

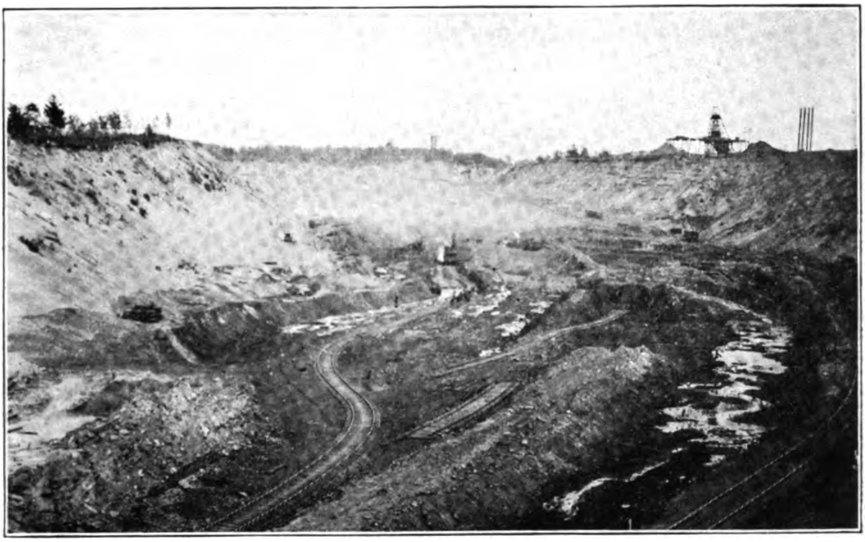
The Adams mine is the easternmost mine on the south range. The area in which it is located was one of the first to be explored in the Cuyuna district. In 1908-9, a shaft was sunk on the property by Rogers Brown Ore Company, but was abandoned at a depth of 52 feet before it had penetrated the surface drift.[100] A few years later the property was leased by Cuyler Adams and a concrete shaft was sunk for him by the New York Foundation Company in 1912. The ore body was opened during 1913, and some ore was shipped in 1914, but during the fall of the latter year operations ceased and the mine has since then been inactive.

The year 1915 was one of considerable activity in the Cuyuna district. Early in the year the concentrating plant at the Rowe mine was started, stripping operations were begun at the Hillcrest mine, about a mile west of Ironton, and at the Armour No. 1 mine north of Ironton, while shaft-sinking was in progress at the Croft mine near Crosby, and at the Rowley mine of the Barrows Mining Company, south of Barrows. A little later stripping operations were begun on the Mahnomen open-pit mine of the Mahnomen Mining Company, north of the Pennington open pit. Toward the latter part of the summer, the Hopkins shaft was sunk by Breitung and Company, Ltd., a short distance east of the Cuyuna-Mille Lacs mine, while in the fall the Tabbert shaft of the Adbar Development Company was started in the south range between Brainerd and Woodrow.

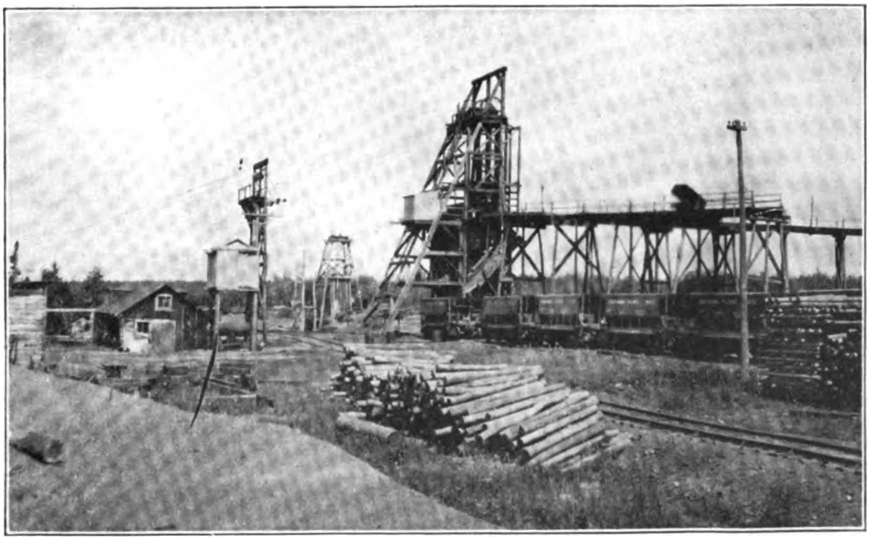
Only three new mines made their initial shipments in 1915, these being the Sultana mine north of Ironton on the north range, the Wilcox mine near Woodrow, and the Brainerd-Cuyuna mine near Brainerd, both on the south range. The Sultana mine of the Sultana Mines Company,

---

[100] Zapffe, Carl, Personal communication.



A. PENNINGTON–ARMOUR NO. I OPEN-PIT MINE NEAR IRONTON. LOOKING NORTHEASTWARD
PHOTO BY CARL ZAPPFE



B. HEAD-FRAME AND TRESTLE OF CUYUNA–MILLE LACS MINE, NEAR IRONTON
LOOKING EASTWARD
PHOTO BY CARL ZAPPFE

UNIV. OF MICH.

formerly the Cuyuna-Sultana Company, is located in the southern part of section 3, T. 46N., R. 29W., about half a mile east of the Cuyuna-Mille Lacs mine, and like the latter is a manganiferous iron-ore mine. The first exploration shaft, which is now Shaft No. 1, was begun June 25, 1914, and the permanent hoisting shaft was begun October 1, 1914. Both were ledged during the fall of 1914. A small quantity of ore was shipped in the fall of 1915, and during the spring and summer of 1916 a considerable tonnage was mined. A small experimental concentrating plant for treating the lower grade ore was erected in the spring of 1915, but tests were unsuccessful.

The sinking of the Wilcox shaft was begun early in 1914 and continued during the summer and fall.[101] The ore body was opened during the winter and the following spring, shipments beginning during the summer. The Wilcox mine is the only one of the south range mines which has produced steadily since it was opened. It was operated by the Canadian-Cuyuna Iron Mining Company during 1915 and 1916. In 1917 it was taken over by the Paterson Construction Company which is operating it at present.

The Brainerd-Cuyuna mine had difficulty in shaft-sinking on account of quicksand. Two shafts were sunk, but were abandoned before reaching bed rock, the first one being started in August, 1913, and the second one in February, 1914.[102] A third one, however, started late in 1914, reached bed rock with difficulty in the spring of 1915. The first ore was raised during the summer, the shipments amounting to 3,000 tons.

During 1916 there was much activity among the manganiferous iron-ore mines, and considerable tonnages of this ore were shipped from the Cuyuna-Mille Lacs, Sultana, Hoch (now Algoma), and Ferro mines. Three new manganiferous iron-ore mines, the Ferro, located near Iron Mountain, the Mangan No. 1 mine situated just northeast of the Cuyuna-Mille Lacs mine, and the Mangan No. 2 mine about one fourth of a mile north of the Armour No. 1 mine near Ironton, joined the list of producers. During the late fall, several new shafts were started on manganiferous iron-ore bodies in different parts of the north range, among them being the shaft of the Merritt interests near Iron Mountain, the McKenzie shaft of the Donohue interests near Manganese, and the Joan shaft of the Joan Mining Company, east of Menomin Lake.

The Ferro mine, formerly known as the Duluth-Brainerd, is located about half a mile southwest of the Algoma mine already mentioned. A shaft was sunk on this property by the Duluth-Brainerd Iron Company during the fall of 1913, and a little ore was taken out.[103] There were no important operations, however, during 1914 and 1915. Early in 1916 the property was taken over by the Onahman Iron Company, and a large tonnage of high-grade manganiferous iron-ore was shipped during the season.

---

[101] Swanson, August, Annual report of Inspector of Mines, Crow Wing County, Minn. Year ending June 30, 1914, p. 13.

[102] *Ibid.*, p. 12.

[103] *Ibid.*, p. 13.

The Mangan No. 1 mine of the Mangan Iron and Steel Company was begun in December, 1915, and a considerable quantity of ore was taken out during the summer and fall of 1916.

The Mangan No. 2 mine, also of the Mangan Iron and Steel Company, contains both iron ore and manganiferous iron ore. Shaft sinking was begun in June, 1916, and a small quantity of manganiferous iron ore was mined during the autumn.

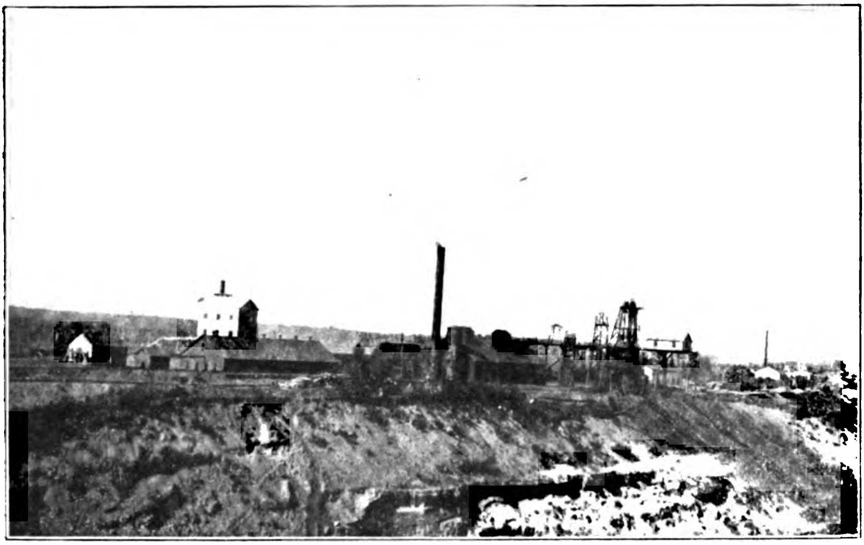
Not only were the manganiferous iron-ore mines active during 1916, but more iron ore was produced in the district than during any previous year. Four new iron-ore mines joined the producing list during 1916, these being the Mahnomen and Hillcrest open-pit mines near Ironton and the Croft and Meacham underground mines near Crosby. A second shaft was started by the Adbar Development Company on the Tabbert property near Woodrow, the first having been abandoned on account of bad ground. This shaft, as well as that at the Rowley mine, near Barrows, had not reached bed rock in the autumn of 1916. Late in the autumn of 1916, the Cuyuna Realty Company started sinking a shaft on the Feigh property, located between the Pennington and Hillcrest open pits.

The Mahnomen ore body was stripped of its overburden by means of steam shovels, operations being started early in the summer of 1915. The work continued during the summer and fall of 1915, and the spring of 1916. As the ore body was underneath a swampy area, considerable difficulty was encountered in excavating on account of water. However, comparatively rapid progress was made, and ore was shipped during the summer and fall of 1916.

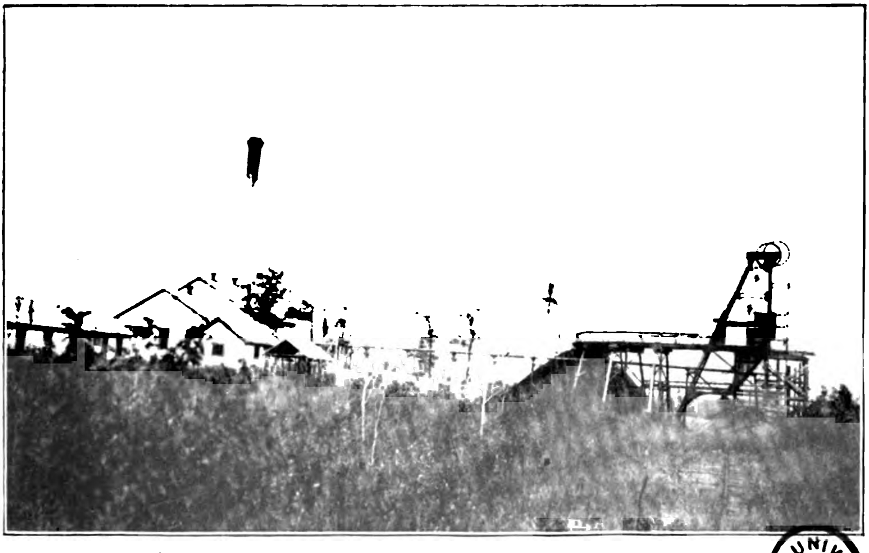
The stripping operations at the Hillcrest mine were commenced in April, 1915,[104] with hydraulic giant and sand pump, such as had been used in removing the overburden from the ore body at the Rowe mine. The average thickness of the overburden overlying the ore body was about sixty-five feet, and it was calculated that approximately a million cubic yards of material had to be removed. The work progressed rapidly during the summer and fall, with an operating force of only six men to a shift, and it continued through the extremely cold weather of January, 1916. During midwinter, however, operations ceased, but were recom-

---

[104] Anon., Stripping the Hillcrest iron mine with a sand pump: *Eng. and Min. Jour.*, vol. 101, pp. 211-215, 1916.



A. HEAD-FRAME, CONCENTRATING PLANT, AND PART OF OPEN PIT AT THOMPSON MINE, NEAR CROSBY. LOOKING NORTHEASTWARD
PHOTO BY CARL ZAPPFE



B. HEAD-FRAME AND POWER HOUSE OF ADAMS MINE, NEAR DEERWOOD
PHOTO BY CARL ZAPPFE

UNIV. OF MICH.

menced in the spring. In the summer the boulders and coarse debris left by the sand pump were removed by means of a steam shovel, and the first ore was shipped from the mine in October. The Hillcrest mine is operated by the Hill Mines Company.

The Croft mine of the Merrimac Mining Company (John A. Savage and Company), is located about half a mile north of Crosby. Shaft sinking was begun at this mine during the fall of 1914 and continued through the summer of 1915. In the fall of 1915, cross cuts were driven from the shaft northward into the ore body, and during the winter and spring the ore body was opened up in preparation for the shipping season. A considerable amount of ore was shipped during the summer and fall of 1916.

The Meacham mine is situated a short distance southwest of the Croft mine near the edge of the Thompson open pit. The shaft was sunk during 1910 and 1911 at approximately the same time that the shafts for the Armour No. 1, Armour No. 2, and Thompson mines were being sunk, but the mine was idle until the spring of 1916, the first shipment being made by Rogers-Brown Ore Company in May.

The iron ore and manganiferous iron ore production from the Cuyuna district to the end of 1916 aggregated 5,116,358 tons, of which 4,747,268 tons were iron ore and 369,090 tons were manganiferous iron ore. This ore was produced by 21 mines, the bulk of it coming from the Kennedy, Armour No. 2, Thompson, Pennington, Rowe, and Armour No. 1. Three mines which contributed to this production, viz., the Adams, Barrows, and Brainerd-Cuyuna mines, were idle in 1916. The remaining 18, however, were actively operated, seven of them making their first production in 1916. The seven new mines are the Croft, Ferro, Hillcrest, Mahnomen, Mangan No. 1, Mangan No. 2, and Meacham. The accompanying table shows the production of the mines of the Cuyuna district to the end of 1916, as reported to the Division of Mineral Resources of the United States Geological Survey.

GENERAL GEOLOGY OF THE DISTRICT

GENERAL STATEMENT

The only known outcrops of bed rock in the Cuyuna iron-ore district are the quartzite and greenstone occurring near Dam Lake and Long Lake, a short distance south of the northeastern end of the iron-bearing belt, and the chlorite schist at Randall near the southwestern end of the iron-bearing belt. Both of these have already been described. Over the rest of the region there is a covering of glacial till varying in thickness from 0 to 400 feet. The variation in thickness of the mantle of glacial material is due in part to the present surface topography and in part to the irregularity of the bed-rock surface. The least thickness

Total Production of Iron Ore and Manganiferous Iron Ore in Cuyuna District†

	1911	1912	1913	1914	1915	1916	TOTAL
Adams	......	......	......	5,505	......	......	5,505
Algoma (Iron Mountain; Hoch)*......	......	......	1,000	......	8,600	23,000	32,600
Armour No. 1........	......	66,526	93,333	......	79,773	76,799	316,431
Armour No. 2........	......	73,089	213,309	238,427	333,856	327,023	1,185,704
Barrows	......	......	18,216	33,540	......	......	51,756
Brainerd-Cuyuna	......	......	......	......	3,000	......	3,000
Croft	......	......	......	......	......	85,033	85,033
Cuyuna-Mille Lacs*.....	......	......	27,200	55,000	45,000	90,000	217,200
Ferro*	......	......	......	......	......	17,210	17,210
Hillcrest*	......	......	......	......	......	22,143	22,143
Ironton	......	......	5,150	44,000	316	35,000	84,466
Kennedy	181,224	205,363	251,984	196,225	202,082	209,777	1,246,655
Mahnomen*	......	......	......	......	......	148,000	148,000
Mangan, Nos. 1* & 2*	......	......	......	......	......	39,572	39,572
Meacham	......	......	......	......	......	56,427	56,427
Pennington	......	......	101,136	......	117,068	206,085	424,289
Rowe	......	......	......	80,000	143,163	174,002	397,165
Sultana*	......	......	......	......	13,152	31,844	44,996
Thompson	......	24,761	32,679	178,354	202,640	197,157	635,591
Wilcox	......	......	......	......	38,708	63,907	102,615
Totals.........	181,224	369,739	744,007	831,051	1,187,358	1,802,979	5,116,358

---

* Manganiferous iron ore mines.

† Statistics compiled by United States Geological Survey, published by permission of mining companies.

known in the principal part of the iron-ore district is 15 feet. Because of this drift mantle the study of the occurrence, structure, and distribution of the various rocks in the Cuyuna district is of necessity based on information gained by drilling and mining operations.

The rocks in the Cuyuna district which have been found up to the present time can all be grouped under three classes, (1) metamorphosed sedimentary and igneous rocks interlayered with each other in beds and lenses, usually with steep dip due to extensive folding, (2) igneous rocks intruded into the metamorphosed rocks subsequent to their metamorphism and deformation, and (3) younger rocks which lie horizontally on the eroded surfaces of the older rocks.

The age of the various rocks is not definitely known. Because of their metamorphosed and folded state, the first group mentioned above has usually been classed as Huronian, and on account of their general relation to the rocks of the Mesabi district and the occurrence of iron-bearing formation in them, it has generally been supposed that they are of the same age as the iron-bearing rocks of the Mesabi district, i.e., upper Huronian.[106]

In accordance with this view all the slates, schists, and other metamorphosed rocks in east central Minnesota have been grouped under the name of Virginia slate, which term was originally applied to the slate overlying the iron-bearing Biwabik formation in the Mesabi district. In view of the facts that no rock outcrops exist in the region between the southwestern end of the Mesabi district and the northeastern end of the Cuyuna district, a distance of nearly 40 miles, and that only scattered drilling has been done in this region, it seems premature to correlate definitely the rocks of the two districts. It is possible that the metamorphosed rocks of the Cuyuna district may belong to either a higher or a lower horizon than the upper Huronian rocks of the Mesabi district, or possibly rocks of several different geologic ages are present. It is undoubtedly true that in most areas of pre-Cambrian rocks in northern United States and Canada, where detailed work has been possible, the occurrence and distribution of the rocks has been shown to be much more complex than is at present supposed to be the case in east central Minnesota. Our present knowledge of the details of the structure and stratigraphy of the rocks of the region is still too meager to allow the substitution of a definite classification for the one now in use. In fact there is no evidence to show that this classification may not be correct. However, it would doubtless have been better had a local term been used for the metamorphosed rocks of the Cuyuna district pending the accumulation of more evidence. In the text of this report general terms preferably are used.

---

[106] Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: *U. S. Geol. Survey Mon.* 52, pp. 212 et seq., 1911.

The old metamorphosed rocks are principally slates and schists of various kinds associated with beds and lenses of iron-bearing formation. Locally quartzite also has been found, and at one or two places limestone is reported to occur. The slates include gray argillaceous slate, finely micaceous gray phyllite, black carbonaceous slate and dark green amphibolitic slate. The schists are principally quartzose and argillaceous sericitic schists, which are probably of sedimentary origin. With these is associated green chloritic schist, much of which appears to be of igneous origin, although the original texture has almost entirely disappeared. Metamorphosed chloritic igneous rocks, in which the schistosity is but slightly developed, however, and in which igneous textures are still clearly visible, have also been found in drilling operations in different parts of the district.

The rocks of second class, viz., igneous rocks which are intrusive into the metamorphosed rocks and have not themselves been metamorphosed, are generally supposed to be of Keweenawan age. If the metamorphosed rocks are of upper Huronian age this is a reasonable assumption. These rocks occur as dikes or irregular intrusive masses of different sizes, cutting the older rocks, and in many instances causing further metamorphism along the contacts. All rocks of this class found in the district up to the present are subsilicic, and are usually medium fine-grained or porphyritic.

The rocks of the third class occur only locally and in minor quantity. They are of two types, (1) horizontal flows of igneous rocks, probably of Keweenawan age, which have been found at one or two places underlying the glacial drift and overlying the metamorphic complex, and (2) isolated patches of ferruginous conglomerate and other sediments supposed to be of Cretaceous age, and probably to be correlated with similar patches of sediments occurring in the western portion of the Mesabi district.[106] The rocks of the first type may perhaps be correlated with the Keweenawan trap rocks found in the region of St. Croix River in eastern Minnesota. No outcrops of them have, however, been found in the central part of the state. The second type of rocks is probably a phase of the clayey and calcareous rocks of Cretaceous age, beds of which occur outcropping along Mississippi River south of Little Falls and elsewhere in central Minnesota.

---

[106] Zapffe, Carl, The Cuyuna iron ore district of Minnesota: *Amer. Ass'n. Adv. Sci.*, Dec. meeting, 1910. See also *Supplement to the Brainerd Tribune*, July 1, 1910.

STRUCTURE OF THE ROCKS

The rocks of the Lake Superior region suffered folding at several periods in their history. As far as is known, however, the forces causing the deformation at the different periods have been applied in approximately the same directions, i.e., northwest-southeast, so that the results, as apparent in the rock structure, are superimposed upon each other. The final outcome of these various deformational activities has been that all the pre-Cambrian rocks of the Lake Superior region have been folded into a great complex synclinorium trending approximately northeast-southwest. The Keweenawan rocks have suffered the least folding of all, and form a broad trough with a gently dipping northwest limb and a more steeply dipping southeast limb. The older rocks have suffered successively greater deformation, the upper Huronian having many minor folds within the main synclinorium, while the lower Huronian and Archean are in places so intensely deformed that it is almost impossible to decipher their relation to the general structure of the region.

Because of the dominance of the northwest-southeast deformation, the general strike of the rock structures, such as bedding, cleavage or schistosity, and folds, throughout the Lake Superior region, varies between east-west and northeast-southwest. It is this general similarity of secondary structures in all the rocks which most strongly points to the conclusion that the deformational movements at different periods have varied but little in direction.

Conforming with the general structure of the Lake Superior region, the rocks of the Cuyuna district are folded into a complex series of anticlines and synclines trending northeast-southwest.[107] In the Cuyuna district the dip of the limbs of the folds is usually vertical or very steep, and may be either to the southeast or northwest, the former dip predominating. Very often close folding has resulted in producing an approximate parallelism of both limbs of a fold. This is probably the explanation for the great predominance of southeast dips in the district, which are characteristic both in the north and south ranges. The pitch of the folds is usually very low and may be either to the northeast or to the southwest. Pitches in one or the other direction usually predominate in different parts of the district. Thus at the southwestern end of the north range the pitch of the folds is in general to the northeast, while along the central part of the north range it is to the southwest. Frequently the pitch is so low that the crests of anticlines are practically horizontal for miles. Because of this low pitch of the folds, the various rock layers appear on the erosion surface as approximately parallel northeast-southwest trending bands. Locally, where the pitch brings rock layers below the erosion surface, sharp turns occur and the bands double back on themselves. Elsewhere minor drag folds cause local irregularities in their trend.

---

[107] Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: *U. S. Geol. Survey Mon.* 52, pp. 620 et seq., 1911.

Zapffe, Carl, The Cuyuna iron ore district of Minnesota: *Amer. Ass'n. Adv. Sci.*, Dec meeting, 1910. See also *Supplement to the Brainerd Tribune,* July 1, 1910.

On account of the lack of exposures and as yet insufficient drilling and underground development, it has not been possible to work out the details of the structure. Drag folds and other secondary structures point to the existence of several major and many minor folds in both the north range and the south range. Ultimately, by means of these structures, it may be possible to determine the relationship between the rocks in different parts of the district. The apparent absence of any definite stratigraphic succession, however, is a serious drawback in working out the geologic relations.

The general distribution and structure of rocks in east central Minnesota indicates that the Cuyuna district is situated near the axis of the southwestern extension of the Lake Superior synclinorium. The close folding, such as exists in this district, would thus be naturally accounted for as well as the very gentle folding along the Mesabi range which is supposed to be on the north limb of the synclinorium. The south limb, represented by the Penokee-Gogebic district in northern Michigan and northern Wisconsin, is as yet unknown in Minnesota. The extensive areas of granitic rock in the Saint Cloud and Mille Lacs Lake regions may be south of the south limb of the synclinorium, or, as believed by Zapffe,[108] they may represent intrusions within the synclinorium. It is known that some of these granites do intrude metamorphosed sediments, but the age of the latter is not definitely established. If the granite is lower-middle Huronian or Laurentian in age and represents the basement upon which the metamorphosed sediments of the Cuyuna district rest, then the south limb of the synclinorium may be expected to run northeastward from Little Falls through the northern part of Mille Lacs Lake toward Kettle River. On the other hand, if the granite is of later age than the metamorphosed sediments and represents intrusions within it, the south limb of the synclinorium may be far to the southeast.

LITHOLOGY OF THE ROCKS

OLDER METAMORPHOSED ROCKS (VIRGINIA SLATE)

Geologic relations.—The principal constituents of the metamorphosed rocks of the Cuyuna district are chloritic, micaceous, and quartzose schists. Associated with these are extensive layers of iron-bearing rock and locally lenses of quartzite and masses of metamorphosed igneous rock. Black, carbonaceous slate and dark green amphibolitic slate also occur in many places, and limestone has been encountered locally. These rocks are irregularly interlayered with each other. They all have a general northeast-southwest strike, and usually a steep dip to the southeast or northwest, the former dip being by far the more common. On the horizontal surface the different rock layers appear as discontinuous bands of varying width all approximately parallel.

---

[108] Zapffe, Carl, *op. cit.*

Up to the present time it has been impossible to work out any definite stratigraphic succession for the metamorphosed rocks of the district. The only horizontal markers of any considerable extent are the layers of iron-bearing rock. These, however, are unsatisfactory since several distinct bands of iron-bearing rock run through different parts of the district, and it is not known as yet whether they are the surface expressions of a single layer which has been complexly folded, or whether several different layers and lenses of iron-bearing rock exist at different stratigraphic horizons. The different bands of iron-bearing rock differ in the character of materials which they contain and in the nature of the wall rock which bounds them. This would indicate that they are not portions of the same layer. On the other hand, the same band of iron-bearing rock may show distinct and even abrupt changes in the nature of the materials composing it, both along the strike and across it. Thus certain bands of iron-bearing rock show highly manganiferous ore along one side and ferruginous chert or hematite with only a trace of manganese along the other side. Other bands of iron-bearing rock consist almost entirely of red or brown hematite and hematitic or limonitic chert in one locality, while at another locality the same band may consist largely of black magnetic ore and magnetitic slate. It is thus difficult to correlate the different bands on the basis of lithology.

Some geologists believe that probably the different bands of iron-bearing rock of the north range may be referred to a single layer, but that the bands in the south range represent a different and probably higher stratigraphic horizon. This assumption is based on the fact that the ore and iron-bearing rock in the two ranges present rather distinct lithologic differences. The south range ore is usually black or yellow and is associated largely with slaty, argillaceous rocks, many of which are magnetitic. Ferruginous chert does not occur as abundantly as on the north range and manganese oxide is present only in small amounts in a few places. The north range ores on the other hand are usually brown, red, or blue, and are abundantly associated with ferruginous chert and only locally with amphibole-magnetite rock or magnetitic slate. They also contain much manganese oxide in places which may be present in distinct bodies or may be disseminated through the iron ore. In view of the facts, however, that much of the north range iron-bearing rock has associated with it slaty, magnetitic rocks, and that the manganese oxide is only local in its occurrence and apparently increases in amount toward the north, it does not seem that the lithologic differences noted between the north range and south range iron-bearing rocks are sufficient to justify their assignment to separate horizons. On account of the unique character of the iron-bearing beds, it is believed that somewhat peculiar conditions attended their deposition. That such conditions were frequently repeated in the course of sedimentation does not seem probable in the absence of definite data to the contrary. It is, therefore, more reasonable for the present to assume that only one main iron-bearing horizon exists in the Cuyuna district. Cheney[109] has recently made an interpretation of the rock structure of the district on this supposition.

What is true of the layers of iron-bearing rock as horizon markers is also true of the associated rocks, and as these in general are much less continuous and less uniform, they are of but little value in this respect. The chloritic schist, which is perhaps the most nearly uniform of these associated rocks, occurs in lenses, which, although of considerable width, are rarely of great longitudinal extent. Such lenses are found at various horizons, frequently being interlayered within the iron-bearing rock itself.

Carbonaceous slate is frequently used as a local horizon marker as it has often been found to occur along the boundary of iron-bearing beds. However, single layers are rarely continuous for long distances along the strike. On the south range, black carbonaceous slate is much more characteristic than on the north range, being so commonly associated with the ore bodies that its presence is considered a good indication for ore.

It might be supposed that quartzite would form a definite stratigraphic unit in this district as it does in most of the other Lake Superior iron-ore districts. However, in the Cuyuna district, quartzite lenses and layers have been encountered in only a few places, and it has not yet been possible to determine any relationship between the scattered occurrences.

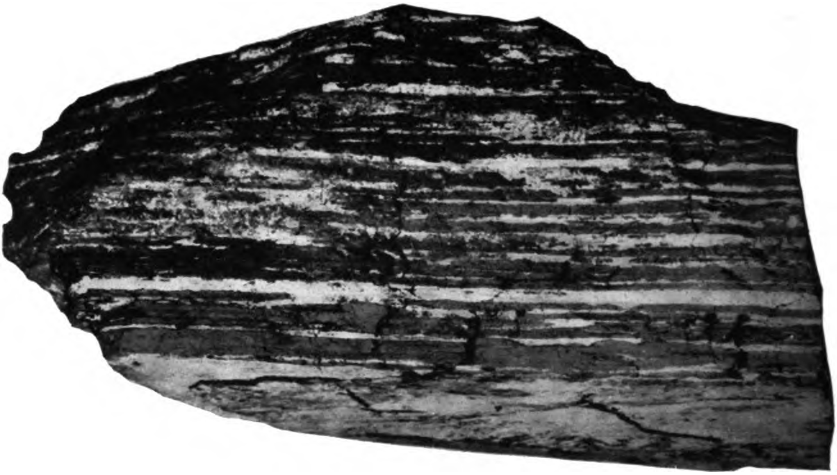
It is possible that, as exploration work progresses, and individual beds of different rocks are traced along the strike, some orderly arrangement of layers may be found to exist. For the present, however, any attempted correlation is largely speculative.

Deerwood iron-bearing member.—The iron-bearing rocks of the Cuyuna district present a variety of lithologic types. Among the more common types are hematitic and limonitic chert, hematitic and limonitic slate, cherty and argillaceous ferrous carbonate, siliceous magnetitic slate, amphibole-magnetite rock, green amphibolitic slate, jaspilite, dark blue,

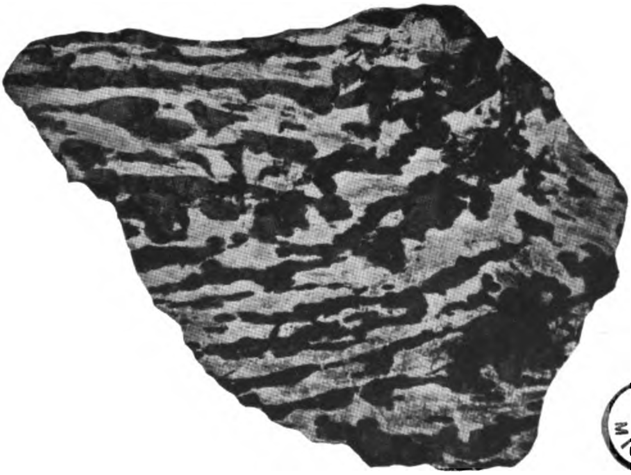
---

[109] Cheney, C. A., Jr., Structure of the Cuyuna iron-ore district of Minnesota: *Eng. and Min. Jour.*, vol. 99, pp. 1113-1115, June 26, 1915.

PLATE XVII



A. FERRUGINOUS CHERT SHOWING REGULAR INTERBANDING OF CHERT AND IRON OXIDE
AFTER APPLEBY AND NEWTON



B. FERRUGINOUS CHERT SHOWING IRREGULAR INTERMIXING OF CHERT AND IRON OXIDE
AFTER APPLEBY AND NEWTON

UNIV. OF MICH.

red, brown, black, and yellow iron ore, black, red, and brown manganiferous iron ore, green chloritic schist, and dark red hematitic schist.

Limonitic and hematitic chert are the most characteristic iron-bearing rocks in the Lake Superior region. In the Cuyuna district they are most abundant in the north range where they compose the principal part of the iron-bearing layers. However, they are common on the south range as well. They usually consist of interlaminated white, pink, or gray chert and hematite or limonite, the chert and iron oxide occurring in alternate layers. (Plates XVII and XVIII.) In some parts of the rock the hematite or limonite laminae are fairly pure, and elsewhere they are very siliceous. In many places the iron oxide present is merely a stain or an impregnation. Thus there are all gradations of ferruginous chert from siliceous iron ore to chert containing only a small percentage of iron oxide. Much of the ferruginous chert, instead of being banded, presents a blotchy appearance due to the irregular distribution of chert and iron oxide or to the irregular staining of the chert by the iron oxide. The more siliceous iron-stained chert usually shows a more irregular distribution of chert and iron oxide. In many places, however, very siliceous ferruginous chert shows an even brown or red color throughout, the entire mass of chert being impregnated with iron oxide.

The chert laminae in ferruginous chert are typically fine-grained, dense, and flinty, but locally they have suffered partial disintegration and present a fine sugary appearance. When completely disintegrated they break up into fine sand, giving rise to what is known as wash ore. Wash ore is soft ferruginous chert from which the disintegrated chert can be removed by washing while the iron oxide remains behind and becomes concentrated.

A microscopic examination of ferruginous chert shows it to consist of little else than silica and iron oxide. A large proportion of the silica present is in the form of slightly recrystallized chert, while the rest is sufficiently coarsely crystalline to be called quartz. Very little chert is amorphous as are cherts of recent geologic age. Most of it has a microcrystalline texture, the coarseness of which varies so that all gradations occur between chert and quartz. The iron oxide is usually amorphous, generally occurring thickly bunched along layers, but at many places also being disseminated through the chert as tiny specks. Locally phases of the ferruginous chert contain iron oxide in the crystalline form.

Hematitic and limonitic slates are not as abundant in the district as ferruginous chert, but occur locally as beds and lenses interlayered with ferruginous chert or iron ore. They are usually dark red or light to dark brown and present a thinly laminated appearance. Red hematitic slate is by far the most abundant. It is dark red, soft, and in general is finely and regularly laminated. The brown limonitic slate is usually more hydrated than the red slate and in places has a soft, clayey consistency. Siliceous phases of the slates which show gradation into ferruginous chert occur also. These are thinly laminated, but are hard and in places contain thin chert layers. The ferruginous slates represent stages in the deposition of the iron-bearing rocks when fine, argillaceous sediment rather than silica was being deposited with the iron. They are generally not slates in the proper sense of the word, as they rarely show slaty cleavage but are rather indurated, ferruginous shales or ferruginous argillites. They are not as abundant in the Cuyuna district as in some of the other Lake Superior iron-ore districts, especially in the Mesabi.

The ferruginous slates differ from the hematitic schist, described on page 119, in that they are sedimentary, having been deposited at the same time as the ferruginous cherts, and having suffered the same alterations. The hematitic schist on the other hand results from the alteration and impregnation with iron oxide of the green chloritic schist, a rock of probable igneous origin, which is commonly associated with the iron-bearing rock. Most of the ferruginous slates cleave parallel to the original bedding laminations; hematitic schist cleaves parallel to the schistosity. Certain ferruginous slates, however, which are derived from the oxidation of green amphibolitic slates also have well-developed secondary cleavage.

Cherty and argillaceous ferrous carbonates are believed to be the original rocks from which the iron-bearing beds of the Cuyuna range in their various phases are largely derived. Such rocks have been reported from many parts of the district, having been found in the deep drilling, and also in the deeper workings of some of the mines. Several different types occur with gradational phases between them. They vary in composition and texture. Some have a banded, laminated appearance while others are massive. Nearly all of them are dense and fine grained. They range from light gray to dark green or black according to the associated minerals present. Usually they consist of interlayered chert or argillaceous material with amphibole and iron carbonate. Magnetite is a common constituent, and with increasing magnetite and recrystallization of the other constituents these rocks grade into amphibole-magnetite rock and magnetitic slate.

The banding of the cherty and argillaceous ferrous carbonate is largely due to interlayering of different constituents. The laminae of chert and siderite are usually light gray or greenish, while those containing argillaceous material or amphibole are darker and with increasing magnetite become almost black. Some phases of iron carbonate rock are light gray and consist almost entirely of chert and siderite which may be interlayered or may be irregularly intermixed. Grains of magnetite often occur along lamination planes, making the banding more marked. Other phases of iron carbonate rock contain considerable amphibole, and these show interbanding of light gray and somewhat darker green layers. Still other phases are very dark gray or green and consist mainly of amphibole and argillaceous material, mixed with more or less siderite but containing little or no chert. Such phases are usually very fine-grained and show no marked lamination. All these varieties of iron carbonate rock are interbedded with each other and grade into each other.

The siliceous magnetitic slate and amphibole-magnetite rock are phases of the original iron-bearing formation which have suffered metamorphic alteration and recrystallization. They are banded or laminated rocks usually very dark colored with a tinge of green. They consist mainly of amphibole and magnetite associated with chert or quartz. The fine-grained, finely laminated types with slaty structures are known as magnetitic slates, while the more coarse-grained and coarsely-layered types are known as amphibole-magnetite rock. As is the case with ferruginous slate, magnetitic slate rarely, if ever, shows slaty cleavage and might perhaps be more properly designated magnetitic argillite. The banding in these rocks is due to the segregation of the different minerals into layers and also to a difference in the coarseness of crystallization. Thus layers of fairly pure magnetite alternate with layers of amphibole or of quartz and amphibole. Some bands are very fine-grained, especially those consisting mainly of magnetite, while other bands as those of amphibole are often medium coarse-grained. The segregation of minerals in the amphibole-magnetite rocks and magnetitic slates is never perfect. Small amounts of magnetite are usually disseminated through quartz and amphibole layers, while quartz, and amphibole occur intermixed with magnetite along the borders of magnetite bands.

There is considerable variation in the composition of these rocks. Some consist largely of magnetite and amphibole and others contain a considerable amount of silica, either as chert or quartz, with amphibole, but with little magnetite. There is also some irregularity in the texture, such as the thickening or pinching out of laminae. These irregularities, however, are much less marked than they are in the ferruginous cherts.

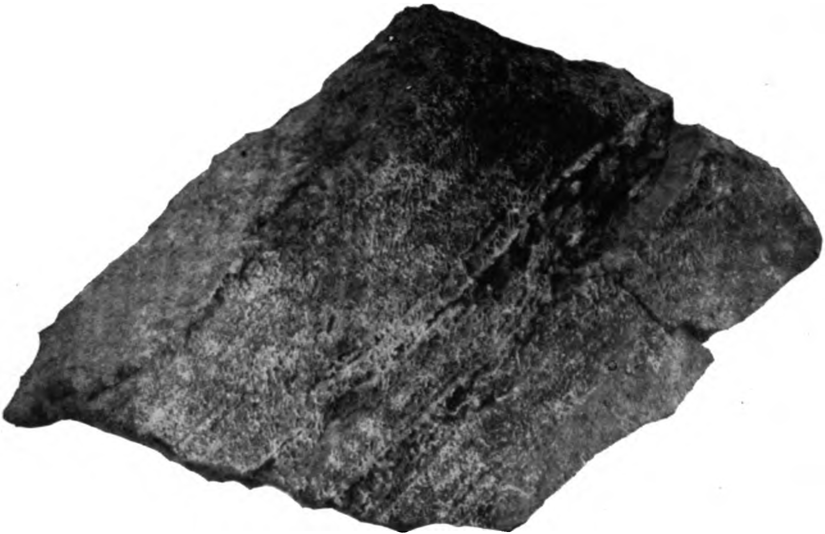
The amphibole-magnetite rock and magnetitic slate of the Cuyuna district differ from the typical amphibole-magnetite rock of some of the other Lake Superior iron-ore districts, such as the Mesabi, Gogebic, and Marquette districts. These rocks in the Cuyuna range are fine-grained, more perfectly laminated, and in general they contain less quartz and more ferromagnesian minerals. The typical amphibole-magnetite rock of the Cuyuna district is a finely banded rock consisting of alternating bands of magnetite and amphibole with a minor amount of quartz. That of the eastern part of the Mesabi district, on the other hand, is an irregularly banded rock consisting of alternating layers of fine-grained magnetite and coarse-grained quartz and amphibole. In the Cuyuna district, quartzose and cherty phases of the amphibole-magnetite rock and magnetitic slate are also common, however, and are characteristic, more especially, of less highly magnetitic phases of these rocks.

With decrease of magnetite and iron carbonate, the slaty iron carbonate rocks and magnetitic slates grade into green amphibolitic slates. These are dark green rocks, nearly always finely and regularly laminated and with well-developed slaty cleavage at varying angles to the lamination. They consist mainly of a network of finely crystalline amphibole, but usually considerable iron carbonate is present and locally magnetite as well. Green amphibolitic slate occurs interbedded with other iron-bearing formation rocks or in areas adjacent to them.

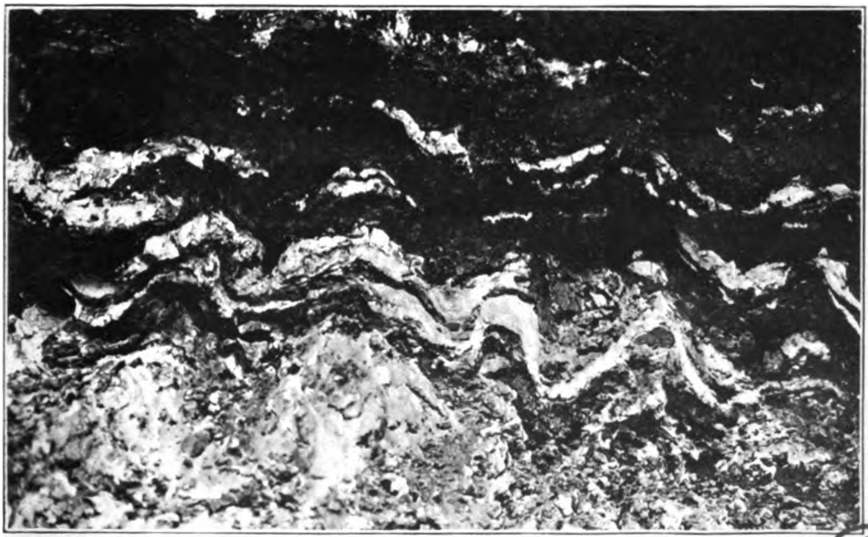
Jaspilite is of rather rare occurrence in the Cuyuna district, but well defined beds of it are found in several of the mines. Thus at the Cuyuna-Mille Lacs mine both the hard red-banded jasper and the specular, schistose jasper occur along the south wall of the north ore body, where they are interlayered between typical banded hematitic chert on one side and lean manganiferous iron ore on the other side.

Jaspilite is metamorphosed and recrystallized ferruginous chert. Where the metamorphism has not been very intense a hard, dense rock, bright red to reddish black, is formed. This is the more common phase, while the crystalline, specular form which results from pronounced recrystallization is more local in its occurrence. Some of the hard, red jaspilite shows oolitic texture. In places in the Cuyuna district there is a very hard, dense, siliceous, ferruginous chert to which the term jasper is sometimes applied. This rock, however, varies in color from brown or reddish brown to black, and is simply a very siliceous ferruginous chert.

The iron ore of the Cuyuna district is associated with different phases of the iron-bearing rock, varying in color, texture, and composition according to the type of iron-bearing rock with which it is associated. Seven or eight main belts of the iron-bearing rocks run in a northeast-southwest direction through the district, and bodies of iron ore or manganiferous iron ore occur at intervals along nearly all of these belts. Both hard and soft ores are found, locally one being more abundant and elsewhere the other. They have suffered varying degrees of hydration. Some consist of typical blue or reddish blue hematite, while others consist of yellow, ocherous limonite. All gradations between these two extremes are found. Some of the rich hematite ore like that at the Armour No. 2 mine is finely crystalline, but most of the ores and especially the more hydrated forms are amorphous. Locally fibrous, botryoidal limonite or goethite occurs in veins and geodes, but does not constitute an important ore.



A. WASH ORE SHOWING POROSITY DUE TO DISINTEGRATION AND REMOVAL OF CHERT AFTER APPLEBY AND NEWTON



B. MINOR PLICATIONS IN THE IRON-BEARING ROCKS AT THE WEST END OF THE ROWE OPEN PIT

UNIV. OF MICH.

The manganiferous iron ore consists mainly of some form of iron oxide mixed with manganite, pyrolusite, or wad. In most of the manganiferous iron ore bodies, local masses of pure black manganese ore occur but are usually present in minor quantity and are irregularly intermixed with manganiferous iron ore or manganiferous iron-bearing rock. The manganiferous iron ores vary in color from dark red or brown to black, and are usually fine-grained to finely crystalline in texture. In a few places vugs of needle ore consisting either of pyrolusite or manganite have been encountered.

The green and gray chloritic schist, commonly known as green schist, and the dark red hematitic schist do not belong to the iron-bearing rocks proper, but are closely associated with them. They generally occur as small lenses within the iron-bearing layers, or they may bound such layers on either side. The dark red hematitic schist usually occurs along the borders of the lenses where the schist is in contact with the iron-bearing rock or iron ore and has become impregnated with iron oxide for varying distances from the contact, while the green or gray chloritic schist occurs in the center of such lenses, or forms entire layers where they are not in contact with iron-bearing rock.

As will be mentioned later, it is believed that the chloritic schists represent original masses of subsilicic igneous rock which were intruded as sills into the iron-bearing rock and associated sedimentary rocks, while these were still largely in an unmetamorphosed condition. Some of it may be of volcanic origin, having been formed as local irregular flows, or as beds of ash or agglomerate. Subsequent metamorphism and deformation were suffered alike by igneous rocks and sediments.

Analyses have been made for the writers by the School of Mines Experiment Station, University of Minnesota, of type specimens of different phases of the iron-bearing and associated rocks with the view of comparing the composition of the different varieties of rock, as well as of determining approximately the range in composition of some varieties. These are given in the accompanying table.

Schist, slate, quartzite, and associated igneous rocks.—The beds of iron-bearing rock practically throughout the Cuyuna district, are inclosed between layers of schist or slate. Generally the schist or slate on one side of the iron-bearing layer is identical with that on the other side. Locally, however, the rocks forming the two walls present marked differences, but such differences are rarely constant over large areas.

A number of distinct types of schist and slate are found in the Cuyuna district, among which are (1) white, greenish or brownish, light-colored, quartzose, sericitic schist or slate, (2) gray, finely micaceous schist, phyllite, or slate, (3) dark green, laminated, amphibolitic slate, (4) dark green or gray chloritic schist, commonly micaceous and locally quartzose,

*Analyses of Type Specimens of Iron-Bearing and Associated Rocks of the Cuyuna District Dried at 212° F.**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Fe_2O_3	50.90†	36.38†	55.50†	32.23†	23.93†	5.27	16.00	1.51	29.57	28.97†	3.70	43.31	12.15	12.24
FeO	.....	.....	.....	.....	.....	31.34	17.33	16.42	17.09	.....	23.70	0.43	24.54	2.41
Mn_3O_4‡	0.27	0.33	.....	1.49	0.36	2.53	1.28	2.27	0.95	0.43	0.50	0.77	6.44	0.23
SiO_2	43.22	59.20	37.68	51.70	47.83	30.15	32.10	59.32	43.24	42.85	28.52	42.70	40.70	37.20
Al_2O_3	0.48	0.27	1.53	8.92	16.62	0.40	4.85	0.79	1.12	18.94	16.78	8.96	2.24	27.39
CaO	0.02	0.02	.....	0.20	0.23	1.25	5.73	0.41	1.56	0.20	1.59	0.28	1.28	0.45
MgO	0.08	0.11	.....	0.03	0.73	4.77	5.74	4.38	2.23	0.03	11.22	0.10	2.77	1.00
K_2O	.....	.....	.....	.....	3.24	.....	.....	.....	.....	.....	.....	.....	.....	.....
P_2O_5	0.073	0.169	0.267	.....	0.176	0.665	4.019	0.057	1.090	0.224	0.987	0.077	0.572	0.316
TiO_2	.....	.....	.....	.....	2.62	0.02	0.13	Trace	0.04	2.06	3.18	0.48	Trace	3.68
CO_2	.....	.....	.....	.....	.....	24.65	8.68	14.06	0.40	.....	.....	0.10	10.21	0.51
Graphite	.....	.....	.....	.....	.....	.....	.....	.....	0.45	.....	.....	.....	0.40	3.75
H_2O (combined)	4.68§	3.92§	5.56§	5.33§	2.74	0.36	3.14	0.25	3.88	6.42	8.48	3.64§	.....	9.14§
Total....	99.72	100.40	100.54	99.90	98.84	101.40	99.00	99.47	101.62	100.12	98.66	100.85	101.30	98.32
Fe { solub. in HCl	35.63	25.15	38.85	22.56	16.04	28.06	24.68	13.83	33.91	20.04	21.02	30.50	26.80	8.80
Fe { insol. in HCl	none	0.32			0.71	none	none	none	0.08	0.24	none	0.08	0.79	1.65
Mn	0.19	0.23	.....	1.05	0.25	1.76	0.89	1.58	0.66	0.30	0.35	0.27	2.24	0.08
P	0.032	0.074	0.117	.....	0.077	0.290	1.755	0.025	0.476	0.098	0.431	0.034	0.250	0.138
Loss on ignition	4.68	3.92	5.56	5.33	3.66	20.65	8.60	12.06	1.05	7.05	7.15	3.64	9.00	9.14

* Analyses by J. H. McCarthy, School of Mines Experiment Station, University of Minnesota.

† Total iron calculated as Fe_2O_3.

‡ Total manganese calculated as Mn_3O_4.

§ Loss on ignition, essentially molecular H_2O.

1. Banded ferruginous chert from Kennedy mine, near Cuyuna, Minnesota (Plate XVII A).
2. Ferruginous chert consisting of irregularly intermixed chert and iron oxide from Thompson mine, near Crosby, Minnesota (Plate XVII B).
3. Hard, dense, ferruginous chert from Rowe mine, near Riverton, Minnesota.
4. Dark red, laminated ferruginous slate from Sultana mine, near Ironton, Minnesota.
5. Soft, red, laminated ferruginous slate from Rowe mine, near Riverton, Minnesota.
6. Fine-grained, light gray, siliceous iron carbonate rock from Kennedy mine, near Cuyuna, Minnesota.
7. Dense, dark gray, argillaceous iron carbonate rock from Kennedy mine, near Cuyuna, Minnesota.
8. Greenish gray, banded, cherty iron carbonate rock from Kennedy mine, near Cuyuna, Minnesota.
9. Greenish black, laminated amphibole-magnetite rock from Adams mine, near Deerwood, Minnesota.
10. Dark red, hematitic schist from Kennedy mine, near Cuyuna, Minnesota.
11. Grayish green, chloritic schist from Kennedy mine, near Cuyuna, Minnesota.
12. Dark red, hematitic slate from Mangan No. 2 mine, near Ironton, Minnesota.
13. Green amphibolitic slate from Mangan No. 2 mine, near Ironton, Minnesota.
14. Black graphitic slate from drill hole north of Blackhoof Lake, near Ironton, Minnesota.

as already described in connection with the iron-bearing rocks, (5) dark red hematitic schist derived from green chloritic schist by impregnation with hematite, (6) dark red hematitic slate derived by oxidation or impregnation with hematite from amphibolitic slate, and (7) black carbonaceous slate, generally containing more or less pyrite. The distribution of these various schists and slates is irregular, but some are more abundant in one locality and others elsewhere. Thus quartzose sericitic schist is especially abundant in the region lying south of the north range, chloritic schist is very common in association with the iron-bearing belts running from Riverton northeastward to Crosby and Cuyuna, while black carbonaceous slate is conspicuous locally in the northeastern portion of the south range and in the northern part of the north range.

Although most of the slate and schist of the Cuyuna district is undoubtedly of sedimentary origin, there are certain types, as the green chloritic schist, which in their occurrence and relation to the associated rocks strongly suggest an igneous origin. The chloritic schist generally occurs in comparatively short thick lenses, which are interlayered with other rocks without any apparent order or regularity, although they generally lie parallel to the bedding of the enclosing rocks. The chloritic schist rarely shows lamination or other sedimentary characteristics, and its contact with the associated rocks is sharp and without gradational phases. Its chemical and mineral composition has not yet been studied in sufficient detail to allow its definite classification, but indications point toward an igneous origin. Much of the light-colored, quartzose, sericitic schist or slate is siliceous, and local phases of it might be termed schistose, sericitic quartzite. The gray phyllite on the other hand is usually very fine-grained and silky in texture and rarely contains much quartz. The green amphibolitic slate consists mainly of a network of finely fibrous amphibole, but contains a considerable percentage of carbonate minerals. This rock is closely associated with the manganiferous iron-bearing rocks north and south of Menomin Lake.

Quartzite has been reported as occurring in several parts of the district, notably in the northeastern portion of the south range and near the southwest end of the north range. In the latter locality, beds of typically fine-grained, vitreous quartzite have been encountered in drilling operations along a belt more than a mile long, beyond which it seems to disappear in the schist areas. Locally iron-bearing rock and black slate are associated with it, but in general chloritic and micaceous schists occur on both sides of the quartzite belt. In the northeastern part of the south range also quartzite has been found by drilling in a number of localities, especially in the neighborhood of Cedar Lake. About 10 or 12 miles east of this region are the quartzite outcrops at Dam Lake. Some connection may exist between the rocks of the two regions.

Igneous rocks, in which the original constituents have been largely altered and which have suffered considerable deformation locally, have been encountered in drilling operations in different parts of the district. Most of them seem to have been originally of a subsilicic character and now consist mainly of chlorite. Some still show the original igneous textures, while others have been rendered schistose and grade into chloritic schist. Gradations between the schistose and non-schistose phases have been found locally.

These rocks are believed to be of approximately the same age as the associated metamorphosed sediments, namely upper Huronian. The less schistose phases are usually medium to fine-grained. When comparatively fresh they are difficult to distinguish from the later igneous intrusives which are believed to be of Keweenawan age. Of the many bodies of igneous rock found in the district, very few except the schistose types can be definitely classified with the earlier or the later group. The relations can be determined only by a careful study of the shape of the igneous rock masses, of the degree of metamorphism which they have suffered, and of their relation to the enclosing rocks.

The form of the masses of igneous rock associated with the metamorphosed sediments has rarely been determined by the drilling, although a few of the masses have been found to be irregularly interlayered with rocks of sedimentary origin. Probably many of them represent intrusions, but some have textures that resemble those of extrusive igneous rocks. In general, however, the alteration has progressed to such an extent that the original character is not determinable from the texture.

LATER INTRUSIVE ROCKS

Later intrusive rocks which are believed to be of Keweenawan age and which have themselves suffered little or no deformation or dynamic metamorphism, are known to occur in many parts of the district. They are practically all of the type usually classed as greenstones, including diorite, diabase, gabbro, and perhaps even less silicic varieties. Most of them are fine-grained dark green rocks of granular or ophitic texture such as occur at the Barrows mine. At one or two localities, as at the Adams mine, a porphyritic rock has been encountered. Many of these intrusive rocks have been altered so that at present they consist mainly of chlorite and decomposed feldspar. Some, however, are still comparatively fresh, having suffered weathering only for a short distance downward from the lower surface of the glacial drift.

The shape of most of the intrusive bodies is not known, as drilling has been conducted so as to avoid them rather than to outline them.[110] Some are known to be in the form of dikes, others are irregular.

---

[110] Zapffe, Carl, The Cuyuna iron-ore district of Minnesota: *Supplement to the Brainerd Tribune*, July 1, 1911.

The metamorphic effect of the intrusions along their contact with the older rock is in most places clearly noticeable. Where the igneous rocks have been intruded into the original iron-bearing rocks, they have usually caused a recrystallization. Chert is changed to quartz, and lime, magnesia, and other constituents are changed to amphibole. The iron oxide is in many places altered to magnetite. Thus typical magnetitic slate and amphibole-magnetite rock have been developed under the action of intrusions. Whether or not most of the rocks of this type in the district have been produced in this manner, or whether they were more generally formed during the deformation is not known. Doubtless the intrusions were locally effective, but from present indications they do not appear to have been sufficiently wide-spread to account for much of the metamorphism over large areas.

LATER VOLCANIC AND SEDIMENTARY ROCKS

Volcanic rocks which lie on the eroded surface of the older rocks are reported by Van Hise and Leith[111] to occur at several localities a short distance south and southwest of Brainerd and also about six miles east of Brainerd. They are said to be silicic and to have amygdaloidal texture. The beds range up to 15 or 25 feet thick and seem to occupy depressions in the underlying rock surface.[112] These volcanic rocks are believed to be of Keweenawan age.

Isolated patches of sediments lying in horizontal beds on the eroded surface of the iron-bearing rocks, schist, and associated rocks have been encountered in drilling and mining operations at a number of localities in the Cuyuna district. These rocks are believed to be of Cretaceous age because of their similarity to isolated patches of Cretaceous rocks in the Mesabi district. Cretaceous rock that bears a similar relation to the underlying metamorphosed rocks, also crops out at several points southwest of the district. In the Cuyuna district proper this rock is a ferruginous conglomerate, consisting of small pebbles of iron-bearing and other rocks in a slaty matrix.[113] Outside of the district the Cretaceous beds consist mainly of sandy and calcareous clay.

OCCURRENCE OF THE IRON-BEARING ROCKS AND IRON ORE

DISTRIBUTION OF IRON-BEARING ROCKS AND ORE

As has been stated, seven or eight main belts of iron-bearing rocks trend approximately northeast-southwest through the district. Some of these are less than a mile long, as, for example, certain belts in the north range and in Morrison County at the southwest end of the south range, while others as the main south range belt extend almost continuously for many miles.

---

[111] Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: *U. S. Geol. Survey Mon.* 52, p. 215, 1911.

[112] Zapffe, Carl, *op. cit.*

[113] *Ibid.*

The most northerly known iron-bearing rocks in east central Minnesota occur in the region of Lake Emily in T. 138N., R. 26W., about 35 miles southwest of the west end of the Mesabi district. The extent of these iron-bearing rocks is as yet only imperfectly known. Farther south bands of low grade iron-bearing rocks are found in T. 136N., R. 26W., and T. 136N., R. 25W., a short distance north of Mississippi River, these being the northeasterly extensions of the northern iron-bearing belts in the north range. Besides these, a few occurrences of iron-bearing rocks are known in the region northwest of Aitkin in T. 137N., R. 25W.

The iron-bearing belts which have so far been found to contain ore bodies of commercial importance are practically confined to the area south and east of Mississippi River in Crow Wing County. However, some ore bodies have been found along the iron-bearing belts in Morrison County west of Mississippi River, although as yet no attempts have been made to develop them. The northerly iron-bearing belts south of Mississippi River are included in the north range and the southerly belts in the south range.

The most northerly north range iron-bearing belt is only indefinitely known. Traces of it occur in section 25, T. 47N., R. 30W., and thence northeastward in sections 20 and 22, T. 47N., R. 29W., beyond which it crosses Mississippi River, as has been noted. No important ore bodies have been found along it.

The next belt of iron-bearing rocks to the south is of considerable importance, containing the manganiferous iron-ore bodies of the Ferro and Algoma mines in sections 32 and 33, T. 47N., R. 29W., and other important ore bodies in sections 28, 22, 27, and 23, T. 47N., R. 29W., the latter in the vicinity of Island Lake. Certain breaks occur in the continuity of the belt, but in general it has been fairly well determined by extensive exploration. The iron-bearing rocks appear to be more or less manganiferous throughout.

South of this belt of manganiferous iron-bearing rock and ore, there are a number of scattered occurrences of iron- and manganese-bearing rocks in the region north and west of Menomin Lake and southwest of Rabbit Lake, such as those in sections 34 and 35, T. 47N., R. 29W. The relation between the separate areas is not yet known. They extend southwestward as far as section 12, T. 46N., R. 30W. To the northeast of them, south of Rabbit Lake, is the important iron-bearing belt containing the Kennedy ore bodies. The Kennedy belt is known from the southern part of section 25, T. 47N., R. 29W., as far east as the eastern part of

Rabbit Lake where it either dies out or turns to the south and doubles back on itself.

A short distance south of the eastern end of the Kennedy iron-bearing belt, is the northeastern end of another belt of iron-bearing rocks which lies to the south. It is uncertain whether these two belts are actually connected. Possibly they form the limbs of a syncline. The southern belt runs southwestward through the northwestern part of section 32 and the centers of section 31, T. 47N., R. 28W., and section 1, T. 46N., R. 29W., into the broad belt of iron- and manganese-bearing formation lying north and northwest of Ironton and Crosby in sections 2, 11, and 10, T. 46N., R. 29W., which contain the Mahnomen and Mangan No. 2 ore bodies along the northern margin and the Thompson north ore body and the Armour No. 1 and Pennington ore bodies along the southern margin. West of the Mahnomen and Pennington mines the belt divides into two parts separated by a strip of slate and schist. The northern part has been explored for only a short distance southwestward into section 9, while the southern part extends southwestward through the Feigh property in section 10, and along the north side of Blackhoof Lake in the southern part of section 9 where it contains the Hillcrest and other ore bodies. Thence it continues through the northwestern corner of section 16 and the northern part of section 17 into section 18, T. 46N., R. 29W., where the Rowe mine is located. Here it makes a synclinal turn northward and doubles back on itself for a short distance. The extent of the backward turn is not yet known.

This iron- and manganese-bearing belt is one of the most important in the district. It is known continuously over a length of more than 8 miles, and along it are some of the most important ore deposits in the district. Unlike the belts to the north, this belt contains many important iron-ore deposits, but manganiferous iron ores are found in it at various places also. On the north it is separated along the central portion, from the Cuyuna–Mille Lacs–Sultana manganiferous iron-bearing area by a thin band of slate or schist, while on the south another thin band of schist separates it from the important Croft-Armour No. 2 iron-bearing belt.

The Cuyuna–Mille Lacs–Sultana manganiferous iron-bearing area is in section 3, south and southeast of Menomin Lake. It is manganiferous throughout and contains important bodies of manganiferous iron ore. It is known to be quite wide where the Sultana and Cuyuna–Mille Lacs mines occur, but its longitudinal extent northeast and southwest is only imperfectly known. Areas of iron-bearing formation, however, occur north and south of June Lake in the northern part of section 9, and these may have some connection with the Cuyuna–Mille Lacs–Sultana area. Other ore bodies occurring in the Cuyuna–Mille Lacs–Sultana ore-bearing area are those of the Mangan No. 1 and the Hopkins mines, the latter containing both iron ore and manganiferous iron ore.

The Croft-Armour No. 2 belt has been well explored to the northeast as far as section 1, T. 46N., R. 29W., where the Croft mine occurs. From this point it runs southwestward through the Meacham, Thompson, Armour No. 2, and Ironton properties in section 11, T. 46N., R. 29W., and continues a short distance into the eastern part of section 10, where it pinches out. The belt is fairly narrow throughout its length, but contains important iron ore bodies. North of the Ironton-Armour No. 2 ore body and the Thompson south ore body which occupy its central portion in section 11, is a band of green schist which separates it from the ore body of the Pennington and Armour No. 1 mines.

The Croft-Armour No. 2 belt consists very largely of iron-bearing formation and associated iron ore, though locally, as in the eastern part of the Armour No. 2 property and the northern part of the Thompson south ore body manganiferous iron-bearing formation and ore occur in it. The proportion of ore to iron-bearing rock in the belt is high, the ore bodies consisting largely of a somewhat siliceous, hydrated, brown to red hematite, but in places containing large masses of red, medium soft, high-grade hematite, some of which is of Bessemer quality. The ore-bearing belt is bounded on the south mainly by green chloritic schist and red hematitic schist.

South of the Croft-Armour No. 2 and the Pennington-Rowe iron-bearing belts, are local occurrences of manganiferous and non-manganiferous iron-bearing formation and ore, such as those in sections 19, 17, 12, and 1, T. 46N., R. 29W. These are the southernmost areas of iron-bearing formation in the north range.

The south range belts of iron-bearing rocks, although narrow, are far more extensive longitudinally than the iron-bearing belts of the north range. The most northeasterly occurrences of south range iron-bearing rock are in the Rice River region northeast of Aitkin. From this point southwestward as far as Deerwood a number of areas of iron-bearing rock are known. They are approximately along the same strike, but there are large unexplored areas between them.

From Deerwood the south range belt of iron-bearing rocks has been traced for about 24 miles more or less continuously southwestward to a point a short distance southwest of Barrows. Mines and exploratory shafts occur along it at intervals where ore bodies have been found, the Adams mine being located in section 30, T. 46N., R. 28W., the Hobart Iron Co. (of Pickands, Mather and Company) shaft in section 8, T. 45N., R. 29W., the Wilcox mine, near Woodrow, in section 13, T. 45N., R. 30W., the Adbar Development Company shaft in section 22, T. 45N., R. 30W., the Brainerd-Cuyuna mine, near Brainerd, in section 36, T. 45N.,

R. 31W., the Barrows mine, near Barrows, in section 10, T. 44N., R. 31W., and the Rowley shaft, also near Barrows, in section 16, T. 44N., R. 31W. Besides the more or less developed ore bodies on which mines and exploratory shafts are located, there are numerous other ore bodies of importance at various points along the belt, as shown by drilling.

Throughout most of its extent, the main south range belt of iron-bearing rocks occurs as a single band. There are, however, small stretches containing two or three parallel bands. In places these are due to a break in a band where the ends are pushed past each other as in a drag fold or thrust fault; elsewhere the repetition has probably resulted from extensive folding. There are also numerous places along the belt where iron-bearing rock has not yet been found, and barren stretches occur which apparently break the continuity of the iron-bearing belt. Future exploration may result in the discovery of iron-bearing formation in such areas.

South and southeast of Brainerd and south of Barrows, a second belt of iron-bearing rock trends parallel to and lies about 1½ miles south of the main south range belt. Ore bodies have been found along it here and there, but it is not yet thoroughly explored.

The Morrison County belts of iron-bearing rock are the continuations of the south range belts west of Mississippi River. Most of them are short. They lie approximately parallel to each other and cover an extensive area in which ore bodies have been found at a number of places.

Isolated bands of iron-bearing rock have been found at several localities south of the south range in Crow Wing County. Among the most important of these is one which contains a considerable amount of iron ore mixed with ferruginous chert, in sections 8 and 9, T. 45N., R. 28W., about halfway between Clearwater Lake and Bay Lake. Another isolated band has been found near Clear Lake in the southern part of T. 46N., R. 25W., and the northern part of T. 45N., R. 25W., in Aitkin County.

The areas between the different belts of iron-bearing rock have been only very imperfectly explored. Practically wherever drilling has been done, however, some variety of schist or slate has been encountered, such as chloritic, amphibolitic, sericitic, quartzose, and graphitic or carbonaceous schist, or slate. Green and gray micaceous and chloritic schist appear to be by far the most abundant. Locally quartzite has been encountered, but usually it is in small amounts, occurring apparently in local lenses. Elsewhere considerable areas of subsilicic igneous rocks have been found.

It is not impossible that as exploration work progresses other areas of iron-bearing rock and ore may be encountered between the belts now known. Drilling has up to the present been confined largely to areas showing abnormal magnetic attraction. Nevertheless iron-bearing rock and ore have been found in several places where no marked abnormal magnetic attraction existed. It seems possible that as the drilling work is extended over larger areas, iron-bearing rock may be found where it is hitherto unsuspected.

The iron-ore bodies are found at intervals along the belts of iron-bearing rock. In some belts they are very abundant, while in other belts they are almost absent. Even along single belts of iron-bearing rock they are more or less grouped in certain parts with stretches of barren iron-bearing rock between. Thus along the Armour No. 2-Thompson belts, ore is almost continuous, while in the Armour No. 1-Pennington belt important ore bodies are grouped together in some parts, and elsewhere they are almost wanting. Other belts, as the main south range belt, have ore bodies scattered along them at irregular intervals with barren areas consisting of ferruginous chert, ferruginous slate, amphibole-magnetite rock, or magnetitic slate between.

OCCURRENCE AND CHARACTER OF ORE

As already stated, the iron-bearing beds are composed of a number of different kinds of rocks. The different varieties vary in abundance in different parts of the district, as well as in different parts of the same belt. The most abundant and most generally distributed of the iron-bearing rocks is the ferruginous chert, and it is with this rock that the iron ore is commonly associated. Ferruginous slate also is abundant, but is not as commonly associated with iron ore. Along the manganiferous iron-bearing belts, however, manganiferous iron ore bodies are frequently found in ferruginous slate as disseminated masses and irregular impregnations. The mining development in the district is not as yet sufficiently advanced to give more than a general idea of the occurrence of the other phases of the iron-bearing rock such as the cherty or argillaceous iron carbonate rock and amphibole-magnetite rock. Iron carbonate rock is usually found at a greater or less depth below other iron-bearing rocks, while amphibole-magnetite rock occurs where metamorphism of the original iron-bearing rock has taken place. Amphibole-magnetite rock is frequently associated with ore, and there is good evidence that certain types of iron ore are closely related with it in origin.

The ferruginous chert occurring in the Cuyuna district is very similar to that found in most of the other Lake Superior iron-ore districts except the Mesabi. In all the Michigan and Wisconsin districts the common rock composing the iron-bearing formation is a more or less regularly banded ferruginous chert, believed by Van Hise and Leith[114] to have been derived by alteration from an original cherty iron carbonate rock. In the Mesabi district the ferruginous chert is largely of the type known as taconite, a rather massive, bedded cherty rock irregularly speckled with iron oxide which is believed to have resulted from the oxidation of the ferrous silicate rock, greenalite rock. No taconite has been found in the Cuyuna district, nor has any greenalite been encountered. It is, therefore, believed that here as in most of the other districts, the original rock from which the present hematitic and limonitic chert and iron ore have in large part been derived is a banded cherty ferrous carbonate rock.

---

[114] Van Hise, C. R., and Leith, C. K., *op. cit.*, pp. 499-560.

It is not the object in this paper to present a discussion on the origin of the iron-bearing rocks and ores. This is reserved for the final report for which more detailed information is being gathered. In view of a recent tendency, however, to question the hypothesis of geologists expressed in earlier reports that most of the iron-bearing formations of the Lake Superior region were deposited originally as ferrous carbonate or silicate, and to supplant it by the hypothesis that the iron was deposited in the ferric form originally, it may be interesting to mention some occurrences in the Cuyuna district which have a bearing on this subject.

Leaving out of consideration the source of the iron, it may be briefly stated that the older hypothesis supposes the iron to have been deposited from the original solutions largely under reducing conditions as ferrous carbonate or ferrous silicate in association with colloidal silica or with argillaceous material. Locally and at certain stages in the deposition, ferric oxide also was probably precipitated, either in a relatively pure form or along with colloidal silica or argillaceous material. However, the ferric oxide deposition is believed to be of relatively minor importance. Eventually these sediments were raised into the belt of weathering and were transformed by surface agencies into their present condition. The ferrous carbonate and ferrous silicate rocks were oxidized to ferruginous chert and ferruginous slate, and the ferruginous chert by the leaching of silica was altered to iron ore. Dynamic metamorphism previous to oxidation in some localities resulted in the alteration of the ferrous carbonate or ferrous silicate to amphibole-magnetite rock, and the latter also was locally in part altered to ore by weathering processes where the previous metamorphism was not very intense.

The other hypothesis differs from this in that the iron is supposed to have been deposited largely as ferric hydroxide, locally in a comparatively pure form, but more generally along with impurities such as colloidal silica or clay. In places the presence of carbonaceous matter or other deoxidizing agents probably resulted in a partial deoxidation of the ferric hydroxide and the formation of local masses of ferrous sediments. Upon metamorphism, these materials were consolidated and in part dehydrated, forming the present ferruginous chert and slate with local original lenses of ore and bodies of ferrous carbonate or ferrous silicate. Later weathering and erosion processes resulted in the formation of additional iron ore by the leaching of silica from the ferruginous chert, and also in the oxidation of some of the ferrous carbonate and ferrous silicate originally present.

The main difference between the two hypotheses is that according to the older one most of the iron-bearing rock was at one time largely in the ferrous state, while according to the later one small masses of ferrous sediments were only locally formed due to the presence in places of deoxidizing agents.

The evidence afforded by the Cuyuna district on this question is largely in favor of the older view. In the exploratory drill work, ferrous carbonate was encountered below a surface capping of ferruginous chert and iron ore, in many parts of the district, while more recently in some of the mining operations ferrous carbonate with associated amphibole-magnetite rock and magnetitic slate has been encountered in the lower levels directly continuous along the bedding with the ore and ferruginous chert of the upper levels. In general, the gradation from ore at the surface through lean ferruginous chert into ferrous rocks below is perhaps more typically illustrated in parts of the Cuyuna district than in any of the other Lake Superior iron-ore districts.

The ferrous carbonate rock of this district, however, differs from the typical cherty iron carbonate rock which has been described from other districts. A number of different phases occur, some cherty, some argillaceous, and others containing amphibole and magnetite. Apparently various gradations occur between ferrous carbonate rock and amphibole-magnetite rock. Their general character and lithology have already been described. Their occurrence is usually irregular. While occasionally magnetitic slate and amphibole-magnetite rock are found practically at bed rock surface, more generally they, as well as the ferrous carbonate rock, are found at some depth. In places, ferrous carbonate rock is also found as masses within the oxidized iron-bearing rocks.

The drilling has not yet been deep enough or thorough enough to give any indication of the average depth at which ferrous rocks are encountered below the oxidized iron-bearing formation phases. At the Kennedy mine, ferrous carbonate rock is abundant on the 262 foot level, while in some other parts of the district drilling has shown ferruginous chert continuing to a depth of 800 feet or more. The depth of oxidation is dependent both on the original nature of the material and on various structural conditions such as fracturing, folding, and faulting.

The average depth to which the Cuyuna ore bodies may be expected to extend is also a doubtful question. It is possible that locally beds of ferruginous chert or ore occur which were originally deposited as such, and these may extend to great depths without much change in their character. On the other hand, where the ferruginous chert was undoubtedly formed by the oxidation of original ferrous sediments and the ore has resulted from the leaching of silica from lean iron-bearing rock, the deposits do not extend to great depths, except perhaps in a few instances where exceptionally favorable structures occur for secondary concentration.

The Cuyuna iron-ore bodies are as a rule roughly tabular in shape, the longer axes being parallel to the bedding of the enclosing rocks. As the beds usually dip steeply, the ore bodies are shown at the surface as bands that extend for considerable distances along the strike of the beds. They vary in width up to several hundred feet, and some of the known ore bodies are more than a mile long. Their behavior with depth varies. Some are comparatively shallow, extending perhaps to a depth of 100 or 200 feet below bed rock surface, where they give way to ferruginous chert, amphibole-magnetite rock, or unaltered iron-bearing rock. Others extend to greater depths, either continuing directly downward along the bedding, or running diagonally downward parallel to the strike in the form of shoots. The data regarding the depths reached by the ore bodies is still very incomplete. The deepest mining operations at present extend to a depth of about 280 feet below the base of the glacial drift, and to this depth ore is known to continue uninterruptedly. The exploratory drill work in the district has for the most part been shallow, few holes occurring which reach a depth greater than 700 feet. Ore, however, has been encountered in some of the deeper holes, and it is suspected that some ore bodies may reach a considerable depth.

The ore bodies are usually enclosed between walls of ferruginous chert, ferruginous slate, or other iron-bearing rocks. Where ferruginous chert forms the wall rock, the contact is usually very irregular. Beds and irregular horses of ferruginous slate and chert are of frequent occurrence in the ore bodies. Green chloritic schist and dark red hematitic schist are also common associates of the iron ore. They may form the wall rock of the ore bodies, or they may occur interlayered with the ore, more or less parallel to the bedding. Other rocks associated with the ore bodies are amphibole-magnetite rock, magnetitic slate, ferrous carbonate rock, green and gray sericitic and siliceous slates, and black carbonaceous slate. These are especially common along the south range, where they form the wall rocks in many places. In the north range, the ferrous rocks in places occur underneath ore bodies representing the unaltered portions of the iron-bearing formation.

Most of the iron ore occurring in the ore bodies of the Cuyuna district is soft, but hard ore is also abundant both in the north and south ranges, and is more or less irregularly associated with the soft ore. The Cuyuna ore probably shows a greater variety of texture, composition, and color than the ore from any of the other Lake Superior iron-ore districts. It shows all stages of hydration from pure reddish blue hematite to ocherous, yellow limonite, and both argillaceous and siliceous phases are common. On the north range the ores vary from dark reddish blue, high-grade hematite, to reddish and yellowish brown siliceous or argillaceous hematite and limonite, while siliceous and argillaceous black, red, and brown manganiferous iron ore is common. Locally wash ore is associated with the other ores. In the south range, the typical ores are reddish brown hydrous hematite, dark brown to black limonite, and yellow, ocherous limonite.

The richest ore that has been found in the district is a medium soft, reddish blue hematite which occurs at the Croft mine and locally in the Armour No. 1, Armour No. 2, Ironton, and Pennington mines in the north range. Much of this ore, especially that at the Croft mine, is of Bessemer quality, samples from the latter deposit analyzing as high as 67 to 68 per cent metallic iron and as low as .01 to .03 per cent phosphorus. While ore of this grade is, of course, exceptional, a large part of the Croft ore body consists of ore of Bessemer quality and will be mined as such. In the other mines no attempt is made to mine the Bessemer ore separately. In the Armour No. 2 and Ironton mines, much of this type of ore is finely crystalline.

The most common ore in the north range is a soft to medium hard, brown to reddish or bluish brown, hydrated hematite and limonite. This ore is locally highly siliceous, and grades with increasing silica into ferruginous chert and wash ore. Much of it also is somewhat argillaceous. Ore of this type is found at the Kennedy, Thompson, Armour No. 1, Armour No. 2, Pennington, and Rowe mines. It usually occurs in somewhat irregular, lenticular bodies of different sizes which are enclosed in or associated with hematitic and limonitic chert and slate. Often ferruginous chert is interbedded with the ore, or occurs in the ore bodies as irregular masses. The character of the ore varies somewhat with the nature of the enclosing rock. Where the wall rock is mainly hematitic slate, as is the case in some of the deposits in the north range, the ore is soft, dark red or bluish red, and usually somewhat argillaceous. On the other hand, where ore is enclosed in ferruginous chert it is medium hard, somewhat siliceous, and generally much fractured, so that it breaks into small blocks. Such ore usually ranges in grade from 58 or 60 per cent metallic iron downward, depending upon the amount of silica or alumina present. The phosphorus ranges from .05 per cent up, and is frequently as high as .4 or .5 per cent. It is generally above .1 per cent.

Another variety of ore found in the north range is the finely laminated, brownish yellow limonite of the Mahnomen open pit. This ore, while usually relatively low in silica, is more hydrated than the other north range ores. The yellow ocherous limonite ore also is common in the south range, where its occurrence is similar to that of the black limonite ore. Usually it is soft and friable. While occasionally argillaceous, as a rule it is quite pure, and ranges up to 56 or 57 per cent in metallic iron, which is nearly the theoretical limit for limonite. Combined moisture in the yellow ocherous ore may run as high as 14 or 15 per cent.

The so-called wash ore of the Cuyuna district has attracted considerable attention, and two washing plants have been erected to treat it. This ore is simply disintegrated ferruginous chert in which the chert is in the form of extremely fine sand, and can readily be washed out, leaving the iron oxide particles behind. The metallic iron content of the ore may be increased in this manner from 8 to 12 per cent.

The soft black limonite ore is common on the south range, but is rare on the north range. It is generally associated with amphibole-magnetite rock and magnetitic slate. As a rule it contains considerable carbonate and is slightly magnetic, owing to disseminated particles of magnetite which occur in it as well as in other south range ores. This magnetite is probably residual from original magnetite-bearing rock which has been altered to ore by the leaching of soluble constituents.

Manganese ore and manganiferous iron ore are common in the north range, especially in the northern part. All gradations occur, from an almost pure manganese ore with only a few per cent of iron, to iron ore with less than one per cent of manganese. The distribution of the different grades of ore is very irregular. Nodules and small bodies of high-grade manganese ore usually occur scattered through low-grade manganiferous iron ore or manganiferous iron-bearing rock. They are too small to be mined separately but are mixed with the manganiferous iron ore. A number of manganese minerals occur in these deposits, chief among which are manganite, pyrolusite, and wad. Any of these minerals may compose the nodules or bodies of manganese ore. Often two or more of them are associated in the same body.

The manganiferous iron ore is usually black, dark red, or dark brown. It occurs in irregular large or small bodies in ferruginous chert or ferruginous slate which may or may not be manganiferous. In places, the manganese-bearing portions of the iron-bearing rocks follow distinct zones more or less parallel to the bedding. The manganese content of the ore bodies varies greatly from place to place. The percentage of manganese commonly ranges from 1 or 2 per cent to 30 or 35 per cent.

Usually a decrease in the percentage of metallic manganese is accompanied by an increase in the percentage of iron, the combined percentage of iron and manganese generally being fairly constant. As the combined percentage of iron and manganese decreases, silica and alumina increase and the material becomes manganiferous iron-bearing formation. Manganiferous iron ore may be soft or hard. Some forms are dense and massive, while others are friable. It is uncertain which of the manganese minerals is associated with the hematite or limonite in the manganiferous iron ore. Possibly all the various manganese oxides are present in different phases of the ore, but it is probable that manganite predominates in the hard ore and pyrolusite and wad in the soft ore.

Iron-bearing rocks in which manganese ore and manganiferous iron ore occur in small and large bodies, are argillaceous or siliceous. Phases of it are very low in manganese, being simply ferruginous chert or ferruginous slate, while other phases are irregularly impregnated with small quantities of manganese oxide throughout, being a manganiferous iron-bearing rock. The bodies of manganese and manganiferous iron ore are found scattered irregularly through these manganese-bearing zones and differ in richness in different parts. As already mentioned the manganiferous iron-bearing rock commonly occupies more or less definite stratigraphic zones of varying width and length in the iron-bearing formation.

The distribution of the manganiferous iron-bearing rocks in the Cuyuna district is somewhat irregular, although in general the more northerly iron-bearing belts are richer in manganese. The south range thus far has not shown the presence of much manganiferous material. Some iron-bearing belts as those on which the Armour No. 1, Armour No. 2, and Thompson mines are situated, have manganiferous iron-bearing rock on the foot wall while other belts such as that on which the Mahnomen open pit is located contain manganiferous material in the hanging wall. In still other localities manganiferous iron-bearing rock and ore may be interbedded with iron-bearing beds. Thus there are all variations in the occurrence of the manganiferous material.

GEOLOGY OF THE PRINCIPAL MINES

NORTH RANGE MINES[135]

FERRO MINE

The Ferro mine of the Onahman Iron Company, is situated in the SE¼ of NE¼, section 32, T. 47N., R. 29W., the shaft being in the foot-wall of the ore body which cuts in a northeast-southwest direction across the southeast corner of the 40-acre tract, dipping steeply to the southeast. The property also includes several adjoining 40-acre tracts.

---

[135] A few field notes made by H. G. Ferguson of the United States Geological Survey in July, 1917, have been inserted in the following descriptions, where indicated.

The ore body in which the Ferro mine is located is near the southwestern end of a belt of manganiferous iron ore and manganiferous iron-bearing formation which extends from the southern part of section 32, T. 47N., R. 29W., northeastward through sections 33, 28, 27, 22, and 23 to about the center of section 24, T. 47N., R. 29W. In general the iron-bearing belt is of varying width, and is bounded on both sides by schist or slate, the nature of which varies at different places along the belt. The iron-bearing rock itself, where affected by surface weathering, consists mainly of ferruginous chert or manganiferous ferruginous chert with which is associated ferruginous slate, manganiferous iron ore and iron ore. With depth, much laminated dark green siliceous rock is encountered which contains ferrous silicates and carbonate mixed with chert.

The Ferro mine has a timber shaft 157 feet deep. The main hauling level is at 149 feet, and the working level from which ore is at present being mined is about 75 feet deep (summer, 1917). The workings are all in iron-bearing rock and ore, no schist having as yet been encountered. The bottom of the shaft is in laminated, greenish black iron-bearing formation which probably consists of a mixture of ferrous carbonate and silicates and chert, the so-called foot-wall of the ore body. A cross-cut to the southwest passes from this rock through the ore body and into dense black ferruginous chert, which forms the hanging wall. The glacial drift overlying the ore body is from 55 to 60 feet thick.

The dip of the bedding of the iron-bearing rocks is from about 65° southeast to vertical, and this is also the range in dip of the ore body. The latter occupies a certain zone in the iron-bearing beds, and apparently represents a replacement of the original rock along this zone by oxides of manganese and iron, chiefly manganese. This is well shown by the fact that the ore occurs along joints and minor cracks, and penetrates from these for varying distances into the mass of the rock. Many little rectangular blocks of ore are found which, on being broken, present an interior of decomposed or partially replaced rock. The nature of the original rock is not known. The character of the rock bounding the ore body leads one to suppose that it probably consisted largely of chert, ferrous carbonate, and ferrous silicate with perhaps considerable manganese carbonate and silicate. The decomposed residue, which at present acts as a sort of matrix in which the ore is embedded and in which it forms replacements, is a dark red, siliceous material rich in iron and usually soft and porous. Associated with the ore are certain layers of epidote rock, the relations of which are not yet known.

The grade of the ore is variable. Masses of rich, finely crystalline pyrolusite occur locally, while elsewhere mixed manganese and iron oxides are found. The matrix of dark red material in which the ore occurs can not be separated from it in mining, so that the ore as shipped ranges between 20 and 30 per cent in metallic manganese and about the same in iron. It is one of the best grades of manganiferous iron ore shipped from the Cuyuna district at the present time.

The following is the average cargo analysis of ore shipped from the Ferro mine during the season 1916.[116]

Average Cargo Analysis of Ore Dried at 212° F. from the Ferro Mine

	Fe	P	SiO_2	Mn	Al_2O_3
Per cent	29.29	.075	17.56	22.29	1.47

JOAN NO. 3[117]

This is a new shaft mine, operated by the Joan Mining Company, situated in the NE¼ of SE¼ of section 32, T. 47N., R. 29W., about 500 feet west-southwest of the Ferro mine, and apparently on the same ore body. Ore is at a depth of 95 feet. The strike is southwest and the dip is steep toward the north and vertical in places. Ferruginous slate, carrying a little carbonate, occurs on the south wall, and changes to limonitic material with bands of chert near the ore. The limonitic ore (partly replaced by manganese) is said to have a higher phosphorus content than the more completely replaced black ore.

ALGOMA MINE

The Algoma mine of the Algoma Mining Company, is about one half mile northeast of the Ferro mine in the NE¼ of NW¼ of section 33, T. 47N., R. 29W. It is located on the same general iron-bearing belt as the latter, although there is apparently a slight break in it between the two properties.

The main hoisting shaft is a lath shaft, which penetrates about 60 feet of surface and about 100 feet of bed rock, while the timber shaft is about the same depth. The principal hauling level is 110 feet deep, and the main present working level is at about 80 feet (summer, 1917). There are several sublevels. As in the Ferro mine, all the workings are in iron-bearing rock and ore, no schist or slate having been encountered. The shaft is in the foot-wall rock, northwest of the ore body.

The ore at the Algoma mine does not occur in a compact body, as that at the Ferro mine, but is found along four or five zones in the iron-bearing formation, running parallel to the bedding of the latter. The zones are separated by ferruginous chert which in some places is hard and siliceous, and elsewhere medium soft and decomposed. Along certain layers it is highly manganiferous, while elsewhere it contains only a trace of manganese. The ore zones vary in width from a few feet to 20 feet or more. Some of them are continuous for a considerable distance along the strike.

---

[116] Lake Superior Iron Ore Association, Analysis of Lake Superior iron ores, season 1916, p. 9, 1917.

[117] Ferguson, H. G.

The material varies in character in the different ore zones, as well as in different parts of the same zone. One zone consists mainly of ocherous, brown iron ore, speckled and blotched with impregnations of manganese ore. Others consist of uniformly black manganiferous iron ore, at some places soft and at others hard and siliceous. At one point a zone of manganiferous iron ore passes into high-grade iron ore along the strike. Thus there is considerable variation in the character as well as in the composition of the ore, and in order to maintain a uniform product, the ore from the different zones is mixed in mining.

The general strike of the ore-bearing beds is perhaps a little more nearly north and south than at the Ferro mine. The dip is steeply southeast. Northeast of the Algoma mine the iron-bearing belt continues across the SE¼ of section 28, where considerable drilling has been done. and where the MacKenzie mine is now being opened up. At this point the belt is wide and consists mainly of ferruginous chert, much of which is manganiferous and locally contains ore. To the northwest of it, green and gray schist have been encountered in drilling, and it seems probable that these rocks also bound the iron-bearing belt to the northwest in the Algoma and Ferro mines. Northeast of section 28, the belt has been explored along the line between sections 27 and 22, and also in section 23, south of Island Lake. At both of these localities it consists mainly of manganiferous iron ore and manganiferous iron-bearing rock. South of Island Lake, the belt is narrow and is highly manganiferous. It is bounded on the north by gray schist and on the south by gray schist and graphitic slate.

The Algoma-Ferro iron-bearing belt, although varying in character in different parts, is distinctly manganiferous throughout its known extent. It varies greatly in width. At some places it is very narrow; in others it is 1,000 feet or more wide. It has a fairly uniform steep dip to the southeast or south. Its extent to the northeast and southwest beyond the present known limits is not yet thoroughly explored. Small areas of iron-bearing formation, however, are known at several localities beyond both ends.

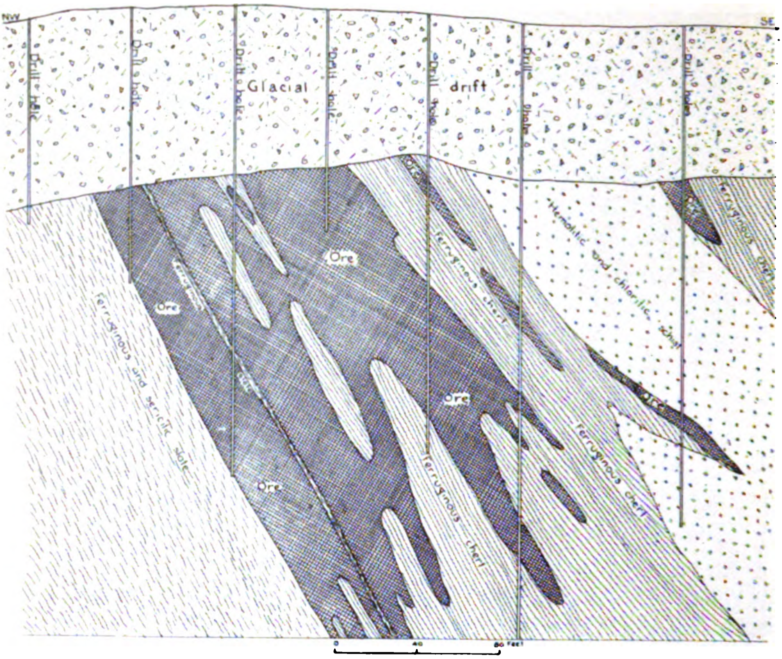
The following is the average cargo analysis of ore shipped from the Algoma (Hoch) mine during the season of 1916.[119]

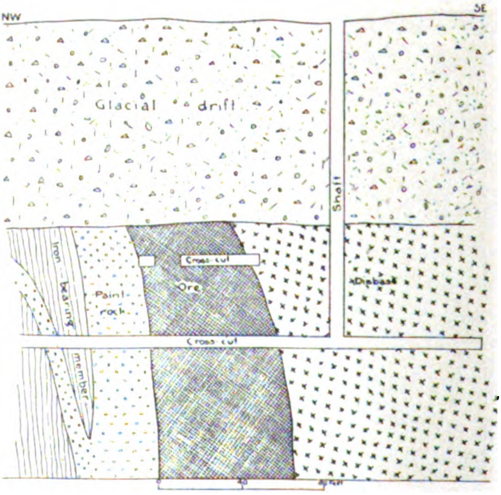
Average Cargo Analysis of Ore Dried at 212° F. from the Algoma Mine

	Fe	P	SiO_2	Mn	Al_2O_3
Per cent....................	32.26	.090	16.47	19.50	2.43

---

[119] Lake Superior Iron Ore Association, *op. cit.*, p. 9.

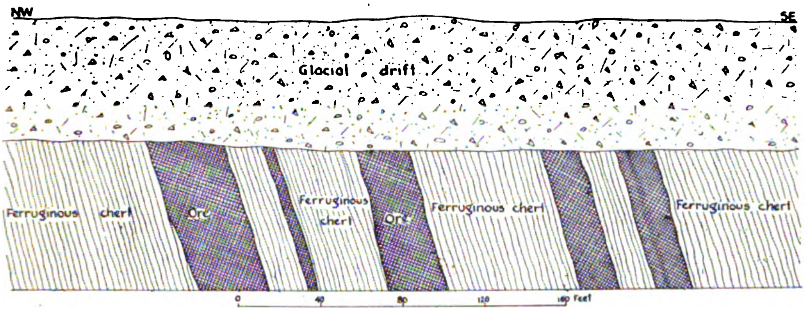

NW
SE
Drill hole
Drill hole
Drill hole
Drill hole
Drill hole
Drill hole
Drill hole
Glacial drift
Ore
Ore
Ore
Ore
Ore
Ore
Ferruginous and sericite slate
Ferruginous chert
Ferruginous chert
Ferruginous chert
Ferruginous chert
Hematitic and chloritic schist
0
40
80 Feet

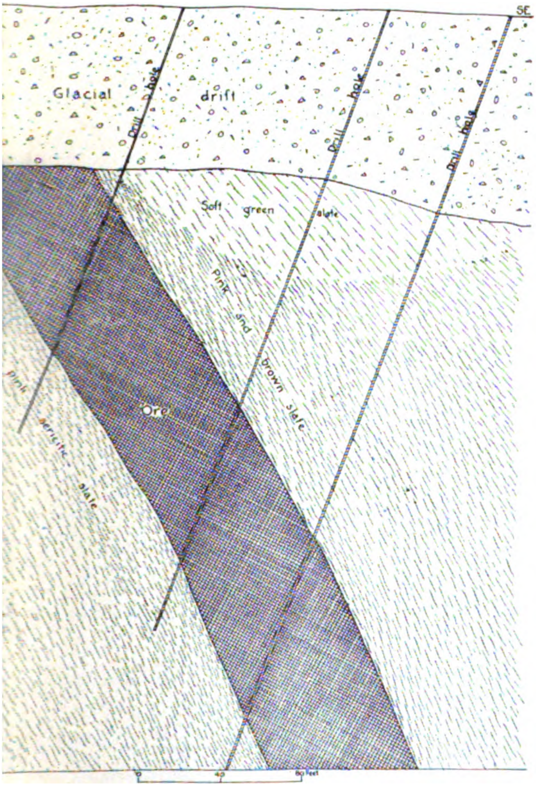

NW
SE
Glacial drift
Shaft
Iron bearing member
Paint rock
Cross-cut
Ore
Diabase
Cross-cut
0
40
80 feet

NW

UNIV. OF

PLATE XIX





TYPES OF ORE DEPOSITS

IN THE

CUYUNA IRON-ORE DISTRICT

MINNESOTA

UNIV. OF MICH.

ROWE MINE

The Rowe mine, operated by the Pittsburgh Steel Ore Company, is located in the N½ of SE¼ of section 18, T. 46N., R. 29W., on Little Rabbit Lake near Riverton, at the western end of the north range. The mine consists of a large open pit about 2,500 feet long, east and west, and about 700 feet wide from crest to crest at the widest part. The depth of the pit at the present time varies from about 100 feet on the north side near the center, to about 20 feet on the south side, the difference being due both to surface topography and to irregularity of excavation (summer, 1917). The overburden, consisting mainly of sand and clay, varies in thickness from 15 feet at the west end of the pit to 74 feet on the north side. The difference in elevation of the ore surface underneath the overburden of glacial till is about 30 feet, thus showing considerable irregularity of the pre-glacial surface over this comparatively small area. The greatest depth of the bottom of the pit below the bed rock surface is about 60 feet, and is near the center of the pit. During the summer of 1917 a concrete hoisting shaft was sunk south of the west end of the pit.

Iron-bearing rock and ore are exposed in the pit over a length of about 1,900 feet and over a maximum width of 450 feet. The general strike of the iron-bearing belt is about N.63°E., but, owing to a sharp synclinal fold at the west end of the pit, the details of the structure within the pit are very complex, as may be seen from the strike and dip readings, shown on Plate XX. The general dip is southeasterly but locally the rocks dip steeply to the north.

The iron-bearing belt has been traced by drilling toward the Rowe mine from the northeast through the north half of section 17. Where it enters section 18 at the east end of the Rowe pit, the iron-bearing belt is about 200 feet wide. Its width gradually increases to the southwest, and near the middle of the pit it has a width of 300 feet. This point marks the beginning of the synclinal turn to the north which occupies the entire west end of the pit. The synclinal fold is composed of a number of minor folds which in turn are composed of smaller folds and crenulations. (Plate XVIII B). Around the end of the turn the outlines of the iron-bearing belt are very irregular, and its width varies between 300 and 600 feet; but beyond the turn on the north limb of the syncline the belt again becomes regular, and decreases in width to between 200 and 300 feet. The turn of the syncline is very sharp, the north limb running back in a northeasterly direction practically parallel to the south limb. Both limbs have a general steep dip to the southeast. The bottom of the syncline pitches to the east between 45° and 60°.

The iron-bearing belt is bounded on both sides by schist and slate. South of the syncline and extending around the west end, is an extensive area underlain by gray and green chloritic and argillaceous schist and slate. Within the syncline, overlying the iron-bearing formation, are light gray siliceous sericitic slate and red ferruginous slate. The latter commonly occurs near the contact of the iron-bearing formation, but is also found within the gray schist. The contact between the red and gray slate is usually irregular and in most cases the red color is due to local staining. Slate or schist are found in the pit in only a few places, the principal exposures being along the center of the north side. The open pit, therefore, is almost entirely in ore and iron-bearing rock.

The iron-bearing rocks at the Rowe mine consist of three distinct types of materials: (1) medium grade hematite and hydrated hematite ore (direct-shipping ore), (2) wash ore, consisting of hematite and hydrated hematite mixed with more or less disintegrated chert, and (3) hard ferruginous chert. These materials are somewhat irregularly distributed and frequently occur intermixed. In some parts of the pit, however, good ore predominates, and in other parts wash ore and ferruginous chert predominate. The latter especially seems to be concentrated along certain lines as is shown on Plate XX. The largest of these areas of ferruginous chert passes lengthwise through the center of the eastern portion of the pit, while another large area occurs in the southern part of the western half of the pit and trends northeasterly. Smaller masses are intermixed both with the wash ore and the direct-shipping ore.

The direct-shipping ore differs from the wash ore and ferruginous chert in that it contains a smaller quantity of impurities such as chert or clay. It consists of a mixture of brown, red, and blue hematite, most of it more or less hydrated. The direct-shipping ore is the principal material in the pit.

The ferruginous chert consists of intermixed hematite and chert. Usually the chert is dense and hard and is white, gray, or pink in color. It may be interlaminated with the hematite in thin irregular layers, or it may be intermixed with it in specks and blotches. This interlayering of light and dark bands is very characteristic of ferruginous chert. In the leaner ferruginous chert the dark bands, instead of being composed of hematite, consist chiefly of chert which has been stained by iron oxide. Usually in such cases the layering is less regular, however.

The wash ore differs from the ferruginous chert in that the chert layers are disintegrated and consist mainly of very fine sand, in places slightly consolidated. This sand is removed by washing and the iron oxide interlayered with it becomes concentrated, the richness of the concentrate depending on the degree of disintegration which the chert has suffered and on the amount of impurity which the hematite layers contain. The hematite interlayered with the chert in wash ore or ferruginous chert may be brown, red, or blue, depending on the amount of hydration which it has undergone.

On the southern side of the iron ore body is a small mass of manganiferous ore, carrying about 43 per cent iron, 15 per cent manganese, and 11 per cent silica, and is apparently a replacement of ferruginous slate. The quantity of manganiferous ore, however, is so small that it is not shipped separately, but mixed with the non-manganiferous iron ore.[120]

The depth to which the Rowe ore body extends is not known. One drill hole near the center of the pit encountered ore to a depth of 360 feet below the original rock surface, while another one located in the angle of the syncline, passed into ore at a depth of 304 feet and continued in merchantable ore for 110 feet. Many encountered ore at a depth of more than 200 feet below the base of the glacial drift. The lower limit of the ore body is probably irregular, the depth varying in different parts, depending upon the attitude and texture of the rock strata. The ore will probably be found to extend to its greatest depth in the western portion of the pit.

The northern limb of the syncline at the Rowe mine consists mainly of ferruginous chert, and as far as known contains but little ore. It has not been thoroughly explored, however, and good ore bodies may be found along it. A minor fold occurs in this limb in the northeastern part of section 18, and beyond this the iron-bearing belt continues northeasterly through the northwest corner of section 17 into section 8. It may be continuous with some of the northern ore belts in sections 9, 3, and 2, T. 46N., R. 29W., in the central part of the north range. However, this connection has not yet been traced out.

HILLCREST MINE

The Hillcrest mine, operated by the Hill Mines Company, is located in the NE¼ of SE¼ of section 9, T. 46N., R. 29W., just northeast of Blackhoof Lake and about one mile west of Ironton. It is approximately on the line of strike of the iron-bearing belt which forms the southern limb of the syncline at the Rowe mine. Iron-bearing rock has been traced almost continuously between the two mines, but it is not yet possible to state definitely whether the iron-bearing formations at the two mines are at the same stratigraphic horizon. However, the iron-bearing rock and associated ore of the Hillcrest mine are known to continue southwestward through the south half of section 9 and into the northwest quarter of section 16, thus leaving a stretch of only about three fourths of a mile of little known territory between this point and the northeast extension of the iron-bearing belt from the Rowe mine.

---

[120] Ferguson, H. G.

Hydraulic stripping operations at the Hillcrest mine were in progress during the summer and autumn of 1915, and during a large part of the winter until stopped by excessive cold. During the summer of 1916 the final stripping was being done with steam shovels. The overburden is 65 to 70 feet thick. The upper part is sand and the lower part is clay containing locally boulders of considerable size.

The iron-bearing rocks and associated ore are known mainly as a result of drilling. The drilling indicates that the iron-bearing belt has a maximum width of 400 feet and is mainly ore over most of its width. The strike of the iron-bearing belt is approximately N.70°E. and the dip is to the south at a fairly steep angle. Locally the beds are vertical. Gray slate and schist bound the iron-bearing belt on the north and south. Near the contact with the iron-bearing rock there is red ferruginous slate or paint rock.

Recently there has been opened at the Hillcrest mine a small lenticular mass of manganiferous iron ore within the iron-ore body. It is bounded on both sides by iron ore with fairly sharp dividing lines. The lens is about 200 feet long by 20 wide, but is somewhat irregular in outline. It represents an impregnation of a part of the ore body by manganese oxide.

Below are given average analyses of ore dried at 212° F. from the Hillcrest mine.[121]

Average Cargo Analyses of Ore Dried at 212° F. from the Hillcrest Mine

	Fe %	P %	SiO_2 %	Mn %	Al_2O_3 %	CaO %	MgO %	S %	Loss by ignition %
Hillcrest.....	58.000	.238	5.500	.230	2.680	.290	.030	.001	6.420
Hillcrest manganiferous	43.811	.230	6.110	9.880	.....	....	....	....	.....

PENNINGTON MINE

The iron-bearing belt of the Hillcrest mine is directly continuous northeastward with the iron-bearing formation of the Pennington and Armour No. 1 mines. The ore bodies, however, are not connected.

The Pennington mine, operated by the Pennington Mining Company of Tod-Stambaugh Company, is an open pit mine situated in the SW¼ of NE¼ of section 10, T. 46N., R. 29W. It is about half a mile from the Hillcrest mine, and the intervening area, which is known as the Feigh property, contains iron-bearing rock throughout its length; with it is associated a considerable quantity of ore. The Pennington pit is about 1,200 feet long, east and west, and has a maximum width of 680 feet from crest to crest. On the east it is directly continuous with the Armour No. 1 open pit which has a length of 750 feet and a width of 550 feet from crest to crest. The depth of the pit formed by these two mines is about 110 feet near the center and about 70 feet at the west end. The overburden of clay and sand above the ore and rock surface averages between 70 and 85 feet thick. The old erosion surface of the ore and iron-bearing rock shows a difference in elevation of about 15 feet in different parts of the pit. Locally ore has been excavated to a depth of 35 to 40 feet beneath the original surface (summer, 1917). The width of ore and rock exposed along the bottom of the pit between the slopes of sand and clay varies from about 400 feet near the center to about 100 feet at the west end. Along the length of the combined pit, ore and iron-bearing rock are exposed for about 1,500 feet.

---

[121] Lake Superior Iron Ore Association, *op. cit.*, p. 9, 1917.

The iron-bearing rock as exposed in the Pennington portion of the pit is very largely ore, some of it of very high grade. Along the north side, however, at the base of the sand slope, there are a few places where hard ferruginous chert is exposed. In the south half of the pit there is a lens of hematitic and chloritic schist varying in width from 50 feet to 120 feet. (Plate XXI.) It is bounded on the north by ore. On the south it is bounded at some places by ore and at others by ferruginous chert. Locally, especially along its north side, the schist lens consists of dark red, soft, hematitic schist or paint rock, but for the most part it is made up of dark green or grayish green fine-grained chloritic schist containing both chlorite and sericite. In general appearance and structure as well as in its relation to the enclosing sedimentary rocks, the chloritic schist suggests a squeezed and altered subsilicic igneous rock. This is true not only of the chloritic schist in the Pennington and Armour No. 1 mines, but elsewhere in the Cuyuna district, practically wherever it occurs. Analyses and microscopic examinations of this rock will probably aid in determining its true character.

The best ore in the Pennington mine is a soft, dark red to reddish blue hematite. It is usually porous and breaks into a mixture of sand and small fragments when handled with the steam shovel. In general it is thinly laminated, and in many places shows crumpling. With increasing silica this ore grades into ordinary laminated ferruginous chert. The ferruginous chert as it occurs in the Pennington mine consists of thin layers of white, pink, or gray chert interlaminated with similar layers of more or less pure hematite, or hydrated hematite or with layers of chert stained dark red or blue by hematite. Thus there are all gradations from chert with certain layers stained by iron oxide to ore with only a very small amount of chert. The different layers or laminae vary in thickness from mere seams to an inch or more. Usually the layers themselves show fine lamination parallel to the bedding. Some ferruginous chert, while showing distinct lamination, does not have continuous layers of different colored materials. The coloration may be irregular, following certain layers for a short distance and then cutting across the lamination, in general giving the rock a blotched appearance. This is especially common in the low-grade ferruginous chert which consists mainly of silica partly stained by iron oxide. Where the rock consists of distinct layers of chert and iron oxide, the layering is usually quite regular and very thin laminae may be followed for several feet. This is well shown locally along the north wall of the pit. In some of the ferruginous chert, the chert layers are partly disintegrated and the rock is soft and readily broken. Elsewhere, however, the rock is dense and extremely hard.

The following average cargo analysis of ore from the Pennington mine is given by the Lake Superior Ore Association.[122]

Average Cargo Analysis of Ore Dried at 212° F. Shipped from the Pennington Mine during the Season of 1916

	Fe %	P %	SiO_2 %	Mn %	Al_2O_3 %	CaO %	MgO %	S %	Loss by ignition %
Per cent.....	58.09	.192	8.26	.31	3.13	.30	.05	.021	4.55

In places in the Pennington portion of the pit, drag folding is conspicuously shown. (Plate XXI.) Three or four well-developed drag folds occur, whose axes trend obliquely across the pit in a direction slightly more north of east than the general strike of the bedding. These drag folds pitch 15° to 30° southwest, and their axial planes dip southeast, indicating that the iron-bearing rock of the Pennington-Armour No. 1 pit is on the south limb of an anticline. This structure is distinctly at variance with the structure as shown at the Rowe mine, where presumably the same iron-bearing layer forms the south limb of a syncline. This discrepancy may indicate that there is a break in the iron-bearing belt between the Hillcrest and Rowe mines.

ARMOUR NO. 1 MINE

The Armour No. 1 mine, operated by the Inland Steel Company, is adjacent to the Pennington mine on the northeast and occurs on the extension of the Pennington ore body. It was operated during 1912 and 1913 as an underground mine, but was idle during 1914. In the spring and summer of 1915 the overburden was stripped and at present the Pennington and Armour mines are both in one big open pit, the Armour No. 1 mine operations being at the east end and the Pennington mine operations at the west end. The first ore was shipped from Armour No. 1 open pit during the fall of 1915.

The Armour No. 1 shaft, a circular concrete shaft, is located south of the ore body in the southern part of the SE¼ of NE¼ of section 10,

---

[122] Lake Superior Iron Ore Association, *op. cit.*, p. 11.

T. 46N., R. 29W. It is 340 feet deep and drifts were run northward to the ore body at the 200 foot and 300 foot levels. The shaft penetrates 65 feet of overburden, and below this it is mainly in green and gray chloritic schist similar to that occurring in places in the present open pit. Locally the schistosity of this rock is not very prominent and the rock is quite massive. About 200 feet north of the shaft on the bed rock surface is the contact between the chloritic schist and the southernmost layer of iron-bearing rock. Iron-bearing rock with associated iron ore and manganiferous iron ore and lenses of green schist and paint rock occupy the northern part of the Armour No. 1 40-acre tract. (Plate XXI.) The Pennington-Armour No. 1 ore body proper is about 500 feet north of the shaft on the bed rock surface.

The general strike of the rock beds is approximately N.70°E., with local variations, and the dip is steeply to the south. The ore body has the same general strike as the rocks. It is cut into two parts longitudinally by a lens of green schist and paint rock that varies up to 100 feet in thickness. This lens pinches out to the west at the boundary of the Pennington property, and to the east it splits into several thin layers separated by ore layers, and gradually pinches out as it approaches the Armour No. 2 property. Unaltered green schist forms the center of the lens, and the paint rock is found along the contact with the ore. The part of the ore body south of the schist lens is bounded on the south by another belt of paint rock and green chloritic schist, which is apparently continuous with the schist lens on the Pennington property. The part of the ore body lying north of the northern schist lens grades northward into manganiferous iron-bearing rock, some of which carries 14 per cent or more of manganese. The ore body including the lens of paint rock and green schist varies up to more than 200 feet in width and extends northeastward across the entire 40-acre tract from the Pennington property line to the Armour No. 2 property line.

The ore is of good grade, ranging on the average between 55 per cent and 62 per cent in metallic iron. It is of non-Bessemer quality, however, ranging in general between 0.15 and 0.3 per cent phosphorus. Its appearance and texture are very similar to the ore on the Pennington property, and seem to be more or less uniform throughout the ore body. The following average cargo analysis of ore from the Armour No. 1 mine is given by the Lake Superior Iron Ore Association.[123]

Average Cargo Analysis of Ore Dried at 212° F. Shipped from the Armour No. 1 Mine during the Season 1916

	Fe	P	SiO_2	Mn	Al_2O_3
Per cent	58.27	.187	7.39	.29	2.47

---

[123] Lake Superior Iron Ore Association, *op. cit.*, p. 8.

IRONTON MINE

The Ironton mine of the Cuyuna-Duluth Iron Company is located just north of the village of Ironton, in the NW¼ of SW¼ of section 11, T. 46N., R. 29W. It consists of a lath shaft which passes through 65 feet of glacial till into underlying green chloritic schist to a total depth of 300 feet. At the 200 and 280 foot levels, drifts run northwestward from it to the ore body, the distance being about 200 feet on the 200 foot level. (Plate XXI.) The ore body is the southwesterly extension of the main Armour No. 2 ore body. It is more or less parallel to the Pennington-Armour No. 1 ore body and is about 1,000 to 1,200 feet southeast of it. Between the two ore belts are green chloritic schist, and paint rock with some lenses of lean iron-bearing rock.

The ore of the Ironton mine is for the most part soft and granular hematite, dark red to reddish blue. It is of high grade and is similar to much of the ore in the western part of the Armour No. 2 mine.

The following average cargo analysis of ore from the Ironton mine is given by the Lake Superior Iron Ore Association.[124]

Average Cargo Analysis of Ore Dried at 212° F. Shipped from Ironton Mine During the Season 1916

	Fe	P	SiO_2	Mn	Al_2O_3
Per cent	59.70	.172	5.75	.81	4.44

ARMOUR NO. 2 MINE

The Armour No. 2 mine of the Inland Steel Company, is located in the SW¼ of NW¼ of section 11, T. 46N., R. 29W. It consists of a circular concrete shaft 298 feet deep and a considerable amount of underground workings. The shaft penetrated 63 feet of glacial overburden, below which it encountered green chloritic schist. The main hauling level is at a depth of 168 feet. At this level, cross-cuts run north-northwestward and south-southeastward from the shaft. (Plate XXI.) The first of these connects with the extension of the 200 foot level of the Armour No. 1 mine in the Pennington-Armour No. 1 ore body, and the second connects with the main Armour No. 2 ore body which continues northeastward from the Ironton mine through the Armour No. 2 40-acre tract. Sublevels are found 127 feet and 107 feet below the surface, and a new exploration drift runs south-southeastward from the shaft at the 258 foot level.

The general strike of the main Armour No. 2 ore body is about N. 55°E. The Pennington-Armour No. 1 ore body strikes N.70°E., thus indicating a convergence of the two ore bodies to the northeast. The main ore belt has a maximum width of more than 400 feet, and, as the dip is at a fairly high angle to the southeast, this gives considerable thickness to the ore body. There is, however, some lean ferruginous chert mixed with the ore, as is the case in nearly all the ore bodies in the Cuyuna district.

---

[124] Lake Superior Iron Ore Association, *op. cit.*, p. 9.

The ore body is of considerable longitudinal extent, for the indications are that it continues northeastward through the adjoining 40-acre tract which also forms part of the Armour No. 2 property, and through the Thompson, Meacham, and Croft properties, a total length of more than one and three fourths miles. However, not enough drilling has been done as yet definitely to prove the continuity of the ore.

There is a curious distribution of different kinds of ore in the ore body on the Armour No. 2 property. The southwestern part of the body, to a point a short distance northeast of the main cross-cut, consists of dark red and reddish blue hematite, usually soft and granular and but slightly hydrated. This ore is high in metallic iron, ranging up to 66 and 67 per cent, and is comparatively low in phosphorus, much of it varying between .02 and .07 per cent. Probably a considerable amount of ore of Bessemer grade could be mined by careful selection. The northeastern part of the ore body consists of an entirely different type of ore. It is largely a medium-hard, brown ore consisting of limonite and hydrated hematite. This ore continues northeastward into the eastern Armour No. 2 40-acre tract, where it locally becomes highly manganiferous, although it contains less manganese than the foot-wall of the Armour No. 1 ore body. The manganiferous iron ore appears to occur as local lenses interlayered with ore and ferruginous chert which is practically free from manganese.

Southeast of the main Armour No. 2 ore body, and forming the hanging wall throughout most of its extent, are beds of hard and rather lean ferruginous chert. Locally, however, in the southwestern half of the ore body, some of the drifts have encountered red, ferruginous slate in the hanging wall directly in contact with the ore. It is probable that drifts driven southward through the ferruginous chert will penetrate it and encounter red hematitic and green chloritic schist south of it similar to that which occurs in the hanging wall of the ore body at the Ironton and Thompson mines.

The foot-wall of the main Armour No. 2 ore body is formed by a layer of paint rock or hematitic schist, which, however, is only 10 or 15 feet thick, and grades into compact green chloritic schist. (Plate XXI.) The latter probably continues northward to the Armour No. 1 ore body, containing locally, however, a few lenses of iron-bearing formation. The main cross-cut running north-northwestward from the shaft to the extension of the Armour No. 1 ore body is entirely in chloritic schist.

The presence of local layers or lenses of iron-bearing formation, however, such as occur also in the Armour No. 1 property, has been shown by drilling.

The extension of the Pennington-Armour No. 1 ore body in the Armour No. 2 property is comparatively thin and appears to become thinner to the northeast. Compared to the main ore body, it is of no great importance. Its hanging wall consists of green chloritic schist, while the foot-wall is formed by iron-bearing formation which is locally manganiferous like that in the Armour No. 1 property. The ore is similar to that in the Armour No. 1 and Pennington mines.

Three grades of ore are shipped from the Armour No. 2 mine.[125]

Average Cargo Analyses of Ore Dried at 212° F. Shipped from the Armour No. 2 Mine during the Season 1916

	Fe	P	SiO_2	Mn	Al_2O_3
Red (per cent)...............	58.20	.104	9.05	.19	3.60
Brown (per cent)...........	54.80	.281	6.94	1.05	3.92
Manganese (per cent)........	49.30	.215	8.90	5.28	3.43

THOMPSON MINE

The Thompson mine of the Inland Steel Company consists of both open pit and underground workings. The latter, however, were not used, except for drainage purposes, between 1913 and 1916, after which date steam shovel operations gave place to milling. The shaft is located in the southern part of the NW¼ of NE¼ of section 11, T. 46N., R. 29W., and the open pit is just south of it on the line between this 40-acre tract and the one immediately to the south.

The shaft, which is 305 feet deep, has cross-cuts north and south at the 150 and 250 foot levels. There is also a sublevel at 100 feet not connected with the shaft. The north cross-cuts encounter an important, but as yet little developed, ore lens located in the northern part of the 40-acre tract in which the shaft is located, and in the southern part of the 40-acre tract adjoining it on the north. This lens is on the line of strike of the Pennington-Armour No. 1 ore body, but drilling has shown that it is a separate lens although it occurs at approximately the same horizon. The south cross-cuts connect with an ore body immediately south of the shaft which is the northeastward extension of the main Armour No. 2 ore body, as has already been mentioned. (Plate XXII.)

The Thompson open pit, which is on the south ore body, has a length of about 1,600 feet and a maximum width from crest to crest near the middle of 450 feet. The overburden, consisting of sand above and of gray and red clay and sand below, varies in thickness from 50 feet to

---

[125] Lake Superior Iron Ore Association, *op. cit.*, p. 8.

80 feet depending upon the topography. The ore surface is comparatively level, although it rises somewhat toward the west. Ore and ferruginous chert are exposed along the bottom of the pit practically throughout its entire length. The width of the bottom of the pit is approximately 100 feet. The bottom in the west end of the pit in the fall of 1915, was about 50 feet below the original ore surface, and in the fall of 1916 about 90 feet below. The strike of the beds is very regular throughout the length of the pit and is about N.65°E. The dip is to the southeast and varies between 50° and 75°, averaging about 65°.

The foot-wall of the ore body which forms the north wall of the lower part of the pit, consists of light gray to dark gray or red siliceous and ferruginous argillite (or slate). It is very thin-bedded and, due to the abundance of silica, has only locally developed slaty cleavage. In places it is stained dark red by hematite. Ferruginous layers are interbedded with siliceous and argillaceous layers. Just below the main ore body a thin lens of ore is interbedded with the foot-wall argillite.

The ore of the main ore body occupies most of the bottom of the pit. In places it consists of almost pure dark brown limonite, while elsewhere it is mixed with sandy disintegrated ferruginous chert or with hard, dense, ferruginous chert. A thin layer of red, ferruginous argillite occurs interbedded with ore in the western part of the pit. The ore as a rule is richest near the foot-wall and for 50 or 60 feet away from it. Toward the hanging wall it becomes more siliceous. Locally along the foot-wall between the ore and the argillite are irregular lenses of manganiferous ore.

The south wall of the pit consists in the western part of hard, massive, ferruginous chert, and in the eastern part of soft, dark red hematitic schist, which is doubtless decomposed and iron-stained chloritic schist, and forms the hanging wall of the iron-bearing formation.

Most of the ore is shipped directly, as it is loaded by steam shovels in the pit, but the hard ferruginous chert occurring with it irregularly along certain horizons is not used. The soft, more or less disintegrated, ferruginous chert is concentrated in a small washing plant equipped with log washers. The following average cargo analysis of ore from the Thompson mine is given by the Lake Superior Iron Ore Association.[126]

Average Cargo Analysis of Ore Dried at 212° F. Shipped from the Thompson Mine during the Season 1916

	Fe	P	SiO_2	Mn	Al_2O_3
Per cent......................	52.34	.250	8.30	2.38	3.44

---

[126] Lake Superior Iron Ore Association, *op. cit.*, p. 11.

The north ore lens of the Thompson mine, as indicated by the drilling, is considerably larger than the south lens. It has a length of about 2,000 feet and a maximum width of 600 feet. Much of it is manganiferous, and it contains considerable iron-bearing rock mixed with the ore. Like the south ore lens, it dips steeply to the southeast. Between the north and south lenses is a great thickness of slate and green chloritic schist with bands of iron-bearing formation.

MEACHAM MINE

The Meacham mine, operated by Rogers-Brown Ore Company, is situated just east of the Thompson open pit on the continuation of the upper or southern Thompson ore body. The property is an 80-acre tract including the NE¼ of NE¼ of section 11, and the NW¼ of NW¼ of section 12, T. 46N., R. 29W.

The shaft, which is located in the NE¼ of NE¼ of section 11, is a circular concrete shaft having a total depth of 254 feet, of which the upper 70 feet are in glacial drift. The main hoisting level is at 154 feet, while the principal working levels at present are at 85, 105, and 115 feet. The shaft is in the foot-wall of the ore body which, like the Thompson ore body, dips steeply to the southeast. The association of ore and wall rocks is similar in the two mines.

The following average cargo analyses of ore from the Meacham mine are given by the Lake Superior Iron Ore Association.[127]

Average Cargo Analyses of Ore Dried at 212° F. Shipped from the Meacham Mine during the Season 1916

	Fe %	P %	SiO_2 %	Mn %	Al_2O_3 %	CaO %	MgO %	S %	Loss by ignition %
Meacham Bessemer..	59.90	.045	3.50	.40	.....	....	....	....	.....
Meacham Non-Bessemer..	55.00	.3347	5.889	.535	3.216	.536	.272	.0139	10.547
Meacham Manganese	46.58	.308	6.52	4.42	4.22	2.08	.55	....	12.02

CROFT MINE

The Croft mine, operated by John A. Savage and Company, is situated one half mile northeast of the Meacham mine on the same iron-bearing belt as the Armour No. 2, Thompson, and Meacham mines. The property comprises the SE¼ of SW¼ and the SE½ of SW¼ of SW¼ of section 1, T. 46N., R. 29W. The western portion of it adjoins the eastern Meacham 40-acre tract on the north.

---

[127] Lake Superior Iron Ore Association, Analyses of Lake Superior iron ores, season 1916, pp. 10 and 11, 1917.

A circular concrete shaft located a short distance northwest of the iron-bearing belt, was sunk through 110 feet of surface drift to the ledge. From its bottom a rectangular steel shaft passes through rock forming the foot-wall of the ore body to a total depth of 250 feet. The main cross-cut, on the 222-foot level, connects the shaft with the various drifts and cross-cuts in the ore body. The main working level is at 160 feet.

Two bands of iron-bearing rock cross the Croft property in an approximately northeast-southwest direction. They are separated by a wedge of green chloritic schist and associated red hematitic schist, which widens to the northeast and comes to a point in the southwestern part of the property. On the northwest and southeast, the iron-bearing belts are bounded by green and red schists. Those to the southeast are chloritic and those to the northwest are locally quartzose, and are probably sedimentary in origin as indicated by their banded and laminated character. The dip of the iron-bearing beds averages about 60° southeast.

The upper iron-bearing bed, i.e., the one to the southeast, consists mainly of ferruginous chert and slate associated with low grade ore, some of which is manganiferous, and with lenses of green and red schist. It has a maximum width of 350 feet on the erosion surface. The mine is located on the lower iron-bearing bed. This bed has an average width of 180 to 200 feet on the erosion surface, but is rather irregular. A part of the layer consists of ferruginous chert associated with some ferruginous slate, and another part of it consists of rich, dark reddish blue hematite which occurs as a layer of varying width running practically through the entire length of the property. Most of the ore, according to drill records, is of Bessemer quality and is the richest ore that has been found in the Cuyuna district. The following average analysis of ore from the Croft mine is given by the Lake Superior Iron Ore Association.[128]

Average Cargo Analysis of Ore, Dried at 212° F., Shipped from the Croft Mine during the Season 1916

	Fe	P	SiO_2	Mn	Al_2O_3	CaO	MgO	S	Loss by ignition
Per cent.....	59.718	.0435	10.250	.110	1.630	.290	.030	.0010	2.600

The depth to which the Croft ore body extends has not yet been shown by drilling. Throughout most of the property it dips southeast more or less parallel to the bedding of the associated rocks and retains a fairly regular thickness with depth. The indications that the ore may extend to a considerable depth are probably as favorable here as they are in any other deposit in the district.

---

[128] Lake Superior Iron Ore Association, *op. cit.*, p. 8.

CUYUNA-MILLE LACS MINE

The Cuyuna-Mille Lacs mine of the Cuyuna-Mille Lacs Iron Company, is located in the SE¼ of SW¼ of section 3, T. 46N., R. 29W., southeast of Menomin Lake, but the property includes also the NW¼ and SW¼ of SW¼ of section 3. The main hoisting shaft, a lath shaft, was sunk through about 50 feet of glacial till and 175 feet of ore and rock to a depth of 225 feet. The timber shaft is 205 feet deep and the main hauling level is at the bottom of it. Both shafts are sunk directly to the Cuyuna-Mille Lacs north ore body. The principal mining operations are now on the 85, 125, 145, 165, and 205 foot levels. At the present time (summer 1917) a second hoisting shaft is being sunk in the SW¼ of SW¼ of section 3. This will connect directly with the south ore body.

The Cuyuna-Mille Lacs north ore body occurs along the crest of an anticline which strikes approximately northeast-southwest. The north limb of the anticline near the ore body has a steep dip northwest, but away from the ore body the beds are overturned, and have a steep dip to the southeast. The south limb of the anticline dips southeast. The dip is fairly low near the ore body, but is higher toward the southeast. The ore body appears to occupy a somewhat indefinite stratigraphic horizon, but its position along the crest of the anticline and its continuation downward along the axial plane suggests that in part, at least, the ore body is a replacement of a fractured zone. Ferruginous chert bounds the ore body on the northwest and southeast. The most characteristic wall rock is an evenly laminated, medium hard, ferruginous chert, which cleaves readily along lamination planes, breaking in thin slabs. This rock is found on both sides of the ore body, but is more characteristically developed on the south side. Some phases of it are rather argillaceous, approaching ferruginous slate in character. At some points along the south side of the ore body, there is a layer of hard, jaspery, ferruginous chert. It is bounded on the north side by low-grade, soft, manganiferous iron ore, and on the south side by the laminated, argillaceous ferruginous chert already mentioned. Up to the present time this jasper layer has not been encountered on the north limb of the anticline. It is probably a local lens.

The structure of the Cuyuna-Mille Lacs anticline with its north limb dipping steeply northward or overturned, and its south limb dipping steeply southward, suggests that it may be a drag fold on the south limb of a more extensive major anticline. South of the ore body for some distance, southeasterly dips of varying steepness prevail, the rocks being mainly iron-bearing formation or manganiferous iron-bearing formation. In the southern part of the SE¼ of SW¼ of section 3, however, a southwestward pitching syncline occurs which is apparently continuous to the northeast with the synclinal trough in the northern part of the Sultana property. The rock strata, however, composing the syncline differ from those found in the Sultana syncline in being more cherty, though slaty layers occur here and there. Several extensive ore lenses are found in the syncline and adjacent to it. They are known collectively as the south ore body.

South of the Cuyuna-Mille Lacs property, in the northern part of section 10 is the Mahnomen open pit. Steep southeasterly dips prevail in the ore at this place, and no secondary structures which might aid in determining the relation of this ore belt to the major structure have so far been found. Lithologically, however, certain manganiferous iron ore layers found in the southern part of the Mahnomen pit are very similar to the manganiferous iron ore of the Sultana and Armour No. 1 mines, and they may represent the same stratigraphic horizon. As already mentioned, the drag folds found along the Pennington-Armour No. 1 ore belt south of the Mahnomen ore belt, indicate that the beds here are on the south limb of a major anticline. Not enough data are as yet available to determine the structural relations of these various beds. It seems probable, however, that a series of folds exists between Menomin Lake and the Pennington pit and results in a repetition of layers. Between which of the ore beds there are anticlines and between which there are synclines can not yet be stated definitely.

The iron-bearing belt in which the Cuyuna-Mille Lacs ore body occurs has been traced continuously only from the southern part of section 4, T. 46N., R. 29W., northeastward through section 3. Little is, therefore, known of its longitudinal extent.

The Cuyuna-Mille Lacs north ore body is compact in form, but the south ore body consists of several separate masses. Both vary considerably in the character of the material from place to place. Locally bodies of rich black manganese ore occur, but the general run of material is a medium soft to hard black or brownish manganiferous iron ore which varies in manganese content from place to place. The rich manganese ore as a rule is finely crystalline pyrolusite; some is fairly hard and compact and some is soft and friable. Dense, hard, black psilomelane is also of frequent occurrence. The manganiferous iron ore usually has a blocky structure and is dense and amorphous. Specks of crystalline material, however, frequently occur scattered through it.

Four grades of ore are mined by the Cuyuna-Mille Lacs Iron Company; the average cargo analyses are as follows:[120]

---

[120] Lake Superior Iron Ore Association, *op. cit.*, p. 9, 1917.

Average Cargo Analyses of Ore Dried at 212° F. Shipped from Cuyuna–Mille Lacs Mine, for the Season 1916

	Fe %	P %	SiO_2 %	Mn %	Al_2O_3 %	CaO %	MgO %
Crow Wing "A".....	37.71	.091	11.46	21.22	.95	.82	.47
Crow Wing "B".....	39.02	.096	13.20	17.06	.42	.84	.67
Crow Wing "C".....	37.39	.79	19.50	12.91	.220	.670	.63
Crow Wing "D".....	40.02	.051	22.00	8.96	.182	.68	.60

The Cuyuna–Mille Lacs mine has been by far the largest shipper of manganiferous iron ore in the Cuyuna district. When the mine was first opened, considerable high-grade ore was produced, but more recently the reserves have been increased by reason of the fact that lower grade ore in large quantities is being shipped.[180] The Cuyuna–Mille Lacs ore contains a considerably lower percentage of phosphorus than the general run of iron ore of the Cuyuna district.

MANGAN NO. 1 MINE

The Mangan No. 1 mine of the Mangan Iron and Steel Company is situated in the NE¼ of SW¼ of section 3, T. 46N., R. 29W., just northeast of the Cuyuna–Mille Lacs mine, being on the northeastern extension of the same ore body. The shaft, a round timber shaft, was sunk to a depth of 122 feet, of which 60 feet are in surface drift and 62 feet in slate and slaty iron carbonate rock. The ore body is south of the shaft. Some ore was mined in the summer and autumn of 1916 and mining continued during 1917.

SULTANA MINE

The Sultana mine, situated east of the Cuyuna–Mille Lacs mine in the SW¼ of SE¼ of section 3, T. 46N., R. 29W., is operated by the Sultana Mines Company. It is in the southern part of the same belt of iron-bearing formation on which are located the Cuyuna–Mille Lacs and Mangan No. 1 mines and the Hopkins shaft. As already mentioned this belt of iron-bearing formation consists typically of a finely laminated, somewhat argillaceous ferruginous chert in the vicinity of the Cuyuna–Mille Lacs ore body. To the southeast across the strike this grades into a denser, more siliceous, ferruginous chert with lamination planes less marked. The portion of the belt along the northeastward extension of which the Sultana mine is located is still farther southeast and consists predominantly of ferruginous slate with local layers of hard, siliceous, ferruginous chert or of more or less decomposed ferruginous chert.

---

[180] Zapffe, Carl, Matters of interest to operators regarding the Cuyuna district: *Proc. Lake Superior Min. Inst.*, vol. 20, p. 197, 1915.

The ore body at the Sultana mine is located in the trough of a northeast-southwest trending syncline[181] with a gently southeastward dipping north limb and a steeply northwestward dipping south limb. It appears to occupy a position farther south relative to the general trend of the iron-bearing belt than the Cuyuna–Mille Lacs anticline, but is more or less parallel to it. This relation seems to indicate that the Cuyuna–Mille Lacs–Sultana iron-bearing belt contains a series of more or less parallel folds whose axial planes dip uniformly to the southeast. The degree of folding varies in different parts, but in general it has been intense, so that isoclinal folds have resulted and the general dip of the beds also is to the southeast. Locally, however, near the axes of the folds northwesterly dips occur.

With the exception of a few small bands of schist, the Sultana 40-acre tract is underlain by iron-bearing rock and associated ore. The bands of schist have a northeast-southwest trend, parallel to the strike of the iron-bearing beds. One band occurs near the southeast corner of the property, north of the eastern end of the Mahnomen open pit, and the other is in the northeastern part. In the northern part of the property, where the ore body occurs, the iron-bearing rock consists mainly of laminated ferruginous slate of which there are two distinct varieties. One of them is the common dark red, medium hard, hematitic slate (or hematitic argillite) and the other a brownish or yellowish, soft, plastic, limonitic clay which becomes medium hard and compact on drying.

As far as can be seen in the present underground workings, the soft, limonitic clay occurs along the northern line of the 40-acre tract and continues some distance southward. It is everywhere finely laminated, due to interlayered light and dark colored laminae. The general strike of the bedding is somewhat north of east. The dip in parts is low to the southeast and in other parts steeply to the northwest. The dark red hematitic slate has been encountered only in a few places. It lies south of the soft limonitic clay and dips steeply to the north or northwest. Ore occurs in both varieties of ferruginous slate, but most of it is in the limonitic phase of the slate.

The main hoisting shaft was sunk directly in the portion of the ore body found in the limonitic clay about 200 feet south of the north line of the property. It is 91 feet deep, and at the bottom of it is the main hauling level. Other levels occur at depths of 65 feet and 75 feet. Cross-cuts run from the shaft northward through the ore body and southward into the dark red hematitic slate. A drift running westward from the main shaft to an exploration shaft in the northwest corner of the property passes through much manganiferous ferruginous slate and chert. Ferruginous chert also occurs locally interlayered with the limonitic clay.

---

[181] Much of the information concerning the Sultana mine was kindly furnished the writers by Mr. H. H. Bradt, Mines Efficiency Co., Duluth, Minn., and Mr. E. Newton, School of Mines Experiment Station, Minneapolis, Minn.

The manganiferous iron ore at the Sultana mine consists of: (1) irregular nodules, lumps, and masses of different sizes scattered through the yellow and brown limonitic clay, and (2) veins and nodules in the dark red hematitic slate (or hematitic argillite). The ore in the limonitic clay is usually dense, amorphous, and hard, although considerably broken up. Its distribution in the clay is most irregular, appearing to be in the form of local replacements.[182] The limonitic clay matrix carries only a very small percentage of manganese except locally, where masses of it appear to have been partly replaced by manganese oxide, but not so completely as to convert it into ore. The origin of the limonitic clay is not clear. It may have been derived from the dark red hematitic slate by hydration and leaching, or the limonitic clay and hematitic slate may both be decomposed phases of ferruginous argillaceous rock which differed somewhat in character and were interbedded with each other. The ore in the hematitic slate is usually very hard and characteristically occurs along joints and fissures. Locally elongated nodules of manganiferous iron ore are found along joints where solutions following the joints have had an opportunity to penetrate the wall rocks on either side. Elsewhere thin veins of nearly pure manganese oxide occur along fissures. Such veins are bounded on both sides by bands of low-grade, reddish black, manganiferous iron ore representing a partial replacement of wall rock, and these low grade bands in turn are bordered with sharp contacts by unaltered hematitic slate.

The following is an average cargo analysis of ore from the Sultana mine:[183]

Average Cargo Analysis of Ore, Dried at 212° F., Shipped from the Sultana Mine during the Season 1916

	Fe	P	SiO_2	Mn	Al_2O_3	CaO	MgO	S	Loss by ignition
Per cent.....	39.302	.170	8.536	13.426	3.50	.75	.50	.015	10.00

HOPKINS MINE

The Hopkins property includes the N½ of SE¼ of section 3, T. 46N., R. 29W., the shaft being located in the NW¼ of SE¼ of section 3, just north of the Sultana mine. The shaft has a depth of 145 feet, about 50 feet being in glacial drift and the rest mainly in a hard, jaspery, ferruginous chert and jaspilite. No ore has been shipped from the mine, the shaft having not yet (summer, 1917) reached the ore body.

---

[182] The ore body at the Sultana mine is a very interesting one as regards structure and origin. A detailed examination of the mine was made by Mr. Harlan H. Bradt, of Duluth, and Mr. Edmund Newton, of Minneapolis, who suggested to the writers the probability that the manganiferous iron ore of the Sultana mine originated by the replacement of an original iron-bearing rock or manganiferous iron-bearing rock by manganese oxide. Subsequently one of the writers (Harder) made an examination of this and other Cuyuna Range manganiferous iron-ore deposits and found that the replacement hypothesis was probably applicable to all of them without exception.

[183] Lake Superior Iron Ore Association, *op. cit.*, p. 11.

The Hopkins mine is located along the same general stratigraphic horizon on which the Cuyuna–Mille Lacs and Mangan No. 1 mines are located, and the jaspilite and hard ferruginous chert which occur in the shaft resemble similar rocks found in the Cuyuna–Mille Lacs mine. Some layers are dark, reddish black, and massive and some are finely laminated and black, dark red, or brown. Laminae of amphibole or hematite, and locally also of carbonate minerals, occur interlayered with the laminae of dark colored chert. Many jasper layers have a well-developed oolitic texture. The rock in general is hard and siliceous.

The shaft was sunk for the purpose of opening up a body of rich hematite ore, but operations were discontinued before the ore was reached. The southern part of the Hopkins property contains the northeastward continuation of the Sultana iron-ore belt.

JOAN MINE[134]

This is a new mine, operated by the Joan Mining Company, located in the SW¼ of NE¼ of section 3, T. 46N., R. 29W., from which shipment of manganiferous ore has just begun. The ore consists of a replacement by manganese oxides of cherty ferruginous material. The outlines of the ore body are irregular, and development work has not yet been carried far enough to determine the extent of the ore. It appears to be a band about 12 feet wide following a generally northerly direction.

MAHNOMEN MINE

The Mahnomen open-pit mine of the Mahnomen Mining Company is in the northern part of section 10, T. 46N., R. 29W. Most of the pit is in the NE¼ of NW¼ and the NW¼ of NE¼ of the section, but the eastern end of it projects for a short distance into the 40-acre tract of the Sultana Mines Company, as well as into the 40-acre tract of the Mangan Iron and Steel Company which comprises the NE¼ of NE¼ of section 10. The location is about half-way between the Pennington open pit and the Sultana mine.

The Mahnomen ore body occurs along the northern edge of a broad belt of iron-bearing rock which extends in a southwest-northeast direction through the northern part of sections 10 and 11, the southeastern part of section 3, and the southern part of section 12, T. 46N., R. 29W. To the southwest it can be traced with interruptions through section 9,

---

[134] Ferguson, H. G.

T. 46N., R. 29W., into section 8, while to the northeast it continues through the northern part of section 1, T. 46N., R. 29W., and through section 31, T. 47N., R. 28W., toward the southeastern part of Rabbit Lake. The details of the structure of this iron-bearing belt, and its relation to the Pennington-Armour No. 1 belt on the south and the Cuyuna–Mille Lacs–Sultana belt on the north, have not been determined. The belts appear to merge into each other, although locally they are separated by schist bands. Development work is constantly progressing, and it will doubtless soon be possible to determine some definite relation between them.

The Mahnomen open pit contains both iron ore and manganiferous iron ore. The iron ore is mainly of the yellow and brown ocherous variety, of porous texture and finely laminated structure, which is not very common on the north range, but is abundant on the south range. Layers of soft red ore, however, are interlayered with the yellow ocherous ore. Little or none of the hard cherty ore common in the Thompson and Armour mines occurs in the Mahnomen open pit. The lamination of the ore is parallel to the general strike of the iron-bearing belt, being somewhat north of east. It dips steeply south for the most part, but locally is vertical, and in many places crumpling has resulted in northerly dips.

The iron ore of the Mahnomen mine is found along the north side of the pit. To the south, across the strike of the beds, it grades into dark red ferruginous slate, locally impregnated with manganiferous iron ore, which in general occupies a band running lengthwise through the center of the pit. The south side of the pit is in manganiferous iron ore associated with yellow clay and some red ferruginous slate. The ore generally occurs as veins and as large and small nodular or irregular masses imbedded in soft yellowish and brownish clayey and slaty material. Some ore is also found in the ferruginous slate layers interbedded with the yellowish and brownish clay, but is less abundant and less rich. The ferruginous slate layers are not numerous along the south wall of the pit, but increase in abundance northward on approaching the red slaty horizon separating the manganiferous iron ore from the iron ore. Here and there are thin layers of gray or variegated, finely laminated, plastic clay very similar to material occurring in the Sultana mine. As has been mentioned, the entire manganiferous bed is strikingly like that of the Sultana mine and may represent the same stratigraphic horizon.

The following grades of ore are offered by the Mahnomen Mining Company, according to the year-book of the Lake Superior Iron Ore Association.[185]

---

[185] Lake Superior Iron Ore Association, *op. cit.*, p. 10.

Average Cargo Analyses of Ore Dried at 212° F. Offered by Mahnomen Mining Company for the Season 1917

	Fe %	P %	SiO %	Mn %	Al_2O_3 %	CaO %	MgO %	S %	Loss by ignition %
Mahnomen......	57.50	.19	6.10	.80	2.67	.98	.42	.054	7.84
Mahnomen No. 1	40.00	.15	10.00	14.00	3.80	.22	.31	.015	7.84
Mahnomen No. 3	46.00	.20	7.55	8.00	3.80	.22	.31	.015	9.84
Mahnomen No. 4	51.00	.19	6.10	4.50	3.70	.75	1.24	.029	9.90

MANGAN NO. 2 MINE

The Mangan No. 2 mine of the Mangan Iron and Steel Company is located in the NE¼ of NE¼ of section 10, T. 46N., R. 29W., just north of the Armour No. 1 40-acre tract and east of the Mahnomen open pit. The southern portion of the property contains the northeastward continuation of the Pennington-Armour No. 1 ore belt, while the northern portion contains the continuation of the Mahnomen ore belt. With the exception of a few schist bands, the entire 40-acre tract is underlain by iron-bearing rock and associated ore. Both iron ore and manganiferous iron ore are present on the property.

The shaft is a round timber shaft. It was sunk during the summer and fall of 1916 to a depth of 100 feet, of which the upper 52 feet are in glacial drift.

KENNEDY MINE

The shafts and principal underground workings of the Kennedy mine, operated by Rogers-Brown Ore Company, are located on the Orelands property, lot 5, section 30, T. 47N., R. 28W. The older underground workings, however, extend also into the SE¼ of SE¼ of section 30, known as the Brown property, and into lot 6 and the SW¼ of SW¼ of section 29, T. 47N., R. 28W., known respectively as the Harrison and Ehric properties.

The mine has a number of shafts, only two of which, however, are in use. The hoisting shaft, which is a wooden drop shaft, is located near the southeastern corner of lot 5, while the timber shaft is near the center of lot 5. The main hauling level is at 262 feet, being at the bottom of the main shaft, but the 150-foot level also connects with the main shaft. Besides these there are numerous sublevels.

The mine is south of Rabbit Lake, at the northeastern end of a belt of iron-bearing rock which is known to extend southwestward a short distance beyond the southwestern end of Rabbit Lake, while to the northeast it runs under the lake. Traces of iron-bearing rock are found farther southwest along the same strike north and northwest of Menomin Lake, but their relation to the Kennedy belt is uncertain. The iron-bearing rock at the Kennedy mine, as indicated by the underground operations, occupies a belt about 1,400 feet wide including ore, ferruginous chert, hematitic schist, and green chloritic schist, all of which occur in irregular bands having a general strike of N.45°E. This broad belt of iron-bearing rock and schist is bounded both on the northwest and southeast by areas of slate and schist, which near the contact of the iron-bearing rock is generally altered to paint rock. This alteration is characteristic also of the chloritic schist included within the iron-bearing beds. The various bands are the expression on a horizontal plane of steeply inclined beds and lenses of different rocks irregularly interlayered. The general dip of the rock layers varies in different parts from 55° to 70° S.E. The hematitic schist and green chloritic schist within the iron-bearing beds are usually in the form of discontinuous lenses more or less parallel to the bedding of the iron-bearing rock. The hematitic schist usually occupies the borders of such lenses and extends for distances varying from a few feet to 50 feet or more into the interior, the unaltered centers being green chloritic schist. Some lenses are all of hematitic schist.

Judging from secondary structures in different parts of the mine, it appears that the entire body of iron-bearing rock is a straight succession. The beds appear to be on the south limb of an anticline, the older rocks occurring along the northwest side of the belt. The iron-bearing rock consists mainly of ferruginous chert with local irregular bodies of iron ore. In places the ferruginous chert is hard and massive, while elsewhere it is partly disintegrated forming wash ore. With depth, the ferruginous chert grades into cherty and argillaceous ferrous carbonate and silicate rocks such as cherty and slaty iron carbonate, amphibole-magnetite rock, and magnetitic slate. These unoxidized phases are especially abundant in the deeper workings of the western and northwestern parts of the mine. Thus above the 210 foot level there is hardly a trace of ferrous rocks, the entire iron-bearing rock being oxidized, while on the 262-foot level the unoxidized phases are abundant. Ferruginous chert, however, is still abundant on the 262-foot level, especially directly underneath the ore bodies where downward circulation has probably been facilitated by the greater porosity of the material. The metamorphosed magnetitic phases of the original iron-bearing rock are more common in the western portion of the workings, the unaltered carbonate phases occurring in the central and northern parts. In the unoxidized parts of the iron-bearing formation in the lower levels, green chloritic schist occurs as it does in the upper levels, but its alteration to red hematitic schist is much less marked. Usually the green schist is in direct contact with the ferrous rocks, and locally it is somewhat difficult to distinguish underground between the argillaceous ferrous rocks and the green schist. In many parts of the mine the schist contains small disseminated crystals of carbonate, probably calcite. In the green chloritic schist these crystals are fresh and transparent, but in the red hematitic schist they are decomposed and form scattered white spots.

There is thus a general gradation in the Kennedy mine from ore, wash ore, ferruginous chert, and hematitic schist in the upper levels, to cherty and argillaceous iron carbonate, amphibole-magnetite rock, magnetitic slate, and green chloritic schist in the lower levels. The occurrence of the different rocks is necessarily somewhat irregular, green chloritic schist being fairly common in the upper levels and ferruginous chert being abundant in the lower levels; nevertheless the general change is very significant.

There are four main ore bodies at the Kennedy mine, which, although irregular, are roughly in the form of lenses parallel to the general trend of the rock layers. They are located in general along a line transverse to the bedding of the rock and have been designated, from northwest to southeast, the (1) north lens, (2) midway lens, (3) intermediate lens, and (4) south lens. The longer axis of each body is parallel to the bedding of the enclosing rocks. Little scattered lenses of ore are found between the main lenses and along their borders. The main shaft is located between the intermediate and south lenses. At the present time only the lenses north of the shaft are producing ore, but in the past considerable ore has been mined from the south lens.

The ore from the different lenses varies somewhat as regards texture and composition. The characteristic ore of the north lens is distinctly laminated, dark reddish to bluish hematite associated with more or less brownish, siliceous, hydrated hematite and limonite. The latter becomes more abundant in the lower levels. The laminated ore is mostly amorphous, but certain layers contain much crystalline hematite. The lamination is caused by the interlayering of ore of different colors, or by the interlayering of siliceous laminae or crystalline laminae with the common amorphous ore. The ore usually breaks along lamination planes, often yielding large slabs.

The principal ore of the midway lens is a soft, yellow to brown, ocherous limonite. Locally masses and fragments of hard, brown limonite occur in it. Bedding is very indistinct and in places wanting.

The intermediate and south lenses consist largely of ordinary hard, amorphous, dark brown limonite or hydrated hematite. Bedding is fairly distinct, but instead of the straight lamination shown by the north lens ore, the bedding planes are irregular and the ore is considerably fractured and crumpled. Much of the ore is of good grade, but much of it is siliceous, grading into ferruginous chert. There seems to be little regularity in the occurrence of the richer or leaner portions.

They are irregularly intermixed. Even the boundary between the ore body and the enclosing ferruginous chert is indefinite. Where the ore lies against hematitic schist, however, as southeast of the intermediate lens, the boundary is sharp.

The differences in the character of the ore lead one to suspect that there were distinct differences in the character of the original iron-bearing formation from which the various types of ore were derived.

The following is an average cargo analysis for ore from the Kennedy mine:[186]

Average Cargo Analysis of Ore, Dried at 212° F., Shipped from the Kennedy Mine during the Season 1916

	Fe	P	SiO_2	Mn	Al_2O_3	CaO	MgO	S	Loss by ignition
Per cent.....	55.09	.241	11.867	.222	1.736	.302	.229	.034	6.09

SOUTH RANGE MINES

ADAMS MINE

The Adams mine is the easternmost mine on the south range, being situated in the SW¼ of NW¼ of section 30, T. 46N., R. 28W. It was operated by Cuyler Adams during 1914, but has since been idle.

The shaft is of concrete and has a depth of 207 feet, the upper 136.5 feet being in glacial drift and the remainder in a dark green, coarsely crystalline diabase. The pump station is at the bottom of the shaft and is excavated in the diabase. From the pump station the main level drift passes first southeastward and then turns and runs in a general southwesterly direction along the ore body. For a short distance, the main drift is in diabase beyond which it penetrates in succession a layer of amphibole magnetite rock and magnetitic slate, a layer of green schist and then another layer of magnetitic slate and amphibole-magnetite rock of considerable thickness, before it encounters the ore body. The layers have a general strike a little north of east and dip steeply south. The magnetitic slate and green schist layers through which the drift passes therefore form the foot-wall of the ore body. Immediately in contact with the ore, the magnetitic slate is oxidized and is soft and clayey, but in general it is hard, dense, and finely laminated. The green schist is soft chloritic schist, usually finely crystalline but showing distinct cleavage.

The diabase through which the shaft passes is dark green in color and consists of a ground-mass of fine-grained, dark green chlorite in which are abundant, long, narrow laths of pink feldspar. These feldspar phenocrysts range in length up to four fifths of an inch, but are rarely wider than one twentieth of an inch. They are scattered irregularly through the rock, giving it a coarse, ophitic texture. Near the bed rock surface the diabase is light brownish green and thoroughly decomposed. On nearing the contact of the magnetitic slate along the main drift, the diabase loses its porphyritic texture and becomes very fine-grained. However, it retains a fine ophitic texture. This clearly indicates that the rock is intrusive.

---

[186] Lake Superior Iron Ore Association, *op. cit.*, p. 10.

The band of iron-bearing rock next to the diabase is a dark-colored, locally almost black, laminated amphibole-magnetite rock. It is hard and dense and in places contains layers several inches thick consisting entirely of dark gray chert. With this are interlaminated thinner layers of black argillaceous rock rich in iron. Locally the chert layers contain abundant brownish fibrous amphibole.

The chloritic schist is distinctly green in color, some being light and some dark. It appears to be of very uniform composition, consisting almost entirely of chlorite. The schistosity varies in different parts. In some places the rock has fine cleavage lines and elsewhere it is more massive. It is fine-grained throughout.

The bed of iron-bearing rock between the chloritic schist and the ore body is of considerable thickness and consists of a mixture of magnetitic slate and amphibole-magnetite rock, the former being more abundant. In general the rocks are more finely laminated and less siliceous than the iron-bearing rock between the diabase and the chloritic schist. The typical magnetitic slate consists of interlaminated light-green, finely crystalline amphibole and black, siliceous or argillaceous, fine-grained magnetite. In some laminae amphibole and magnetite are intermixed and then form greenish black layers. The laminae vary in thickness, usually being very fine, but in places ranging up to half an inch thick. The rock cleaves readily along lamination planes. The proportion of chert or quartz present is small in the magnetitic slate, and with increasing siliceous material and coarser layering the slate grades into amphibole-magnetite rock. Thin pyrite veins occur in both the magnetitic slate and amphibole-magnetite rock.

The ore of the Adams mine varies greatly in character and appearance. Some of it is finely laminated and medium soft, while some is hard. In color it usually ranges from dark brown or red to black, the more hydrated ore being dark brown. Some of the finely laminated varieties, although of good grade, show a greenish or grayish tint, as if they contained much clay. The ore in general is of good grade.

HOBART EXPLORATION SHAFT

The exploration shaft of the Hobart Iron Company of Pickands, Mather and Company, is situated in the SW¼ of SE¼ of section 8, T.

45N., R. 29W. It is about two miles east of Woodrow and is on the same general iron-bearing belt on which the Wilcox mine at Woodrow is located. Several minor breaks, however, occur in the belt between the two localities.

The shaft has a depth of 120 feet, of which the upper 76 feet are in glacial drift. Its bottom is in magnetitic iron-bearing rock while a cross-cut 205 feet long running southward from it at the 114-foot level passes through 165 feet of mixed magnetitic iron-bearing rock and ore into green slate. The beds are very steep, having an average dip of about 80°SE. The green slate forms the hanging wall of the iron-bearing bed. The foot-wall is not shown in the workings.

The iron-bearing bed contains a number of different kinds of rock. The shaft is mainly in finely laminated, black, magnetitic slate and lean magnetic ore. Much of this material, especially near the surface, is oxidized to a brown or brownish red, siliceous limonite. Near the bottom of the shaft, in the cross-cut, is a rather massive, fine-grained, dark green chlorite rock. Some of this is dense, but some of it contains small rhombic cavities from which crystals of carbonate have evidently been leached. Southward from the chlorite rock, the cross-cut passes through different kinds of black or dark green cherty and slaty iron-bearing rocks, some bands of which average over 50 per cent in metallic iron. In some of the beds, distinct layers of dark-colored chert appear, while other beds contain much green argillaceous rock. In general, however, the material is black, finely laminated, hard, lean ore. Much of it is slightly magnetic, but much has been completely oxidized and hydrated to a dense, brownish black, siliceous limonite. A drift runs eastward from the cross-cut in this lean ore for a distance of 80 feet.

The hanging wall slate is in part argillaceous and in part chloritic. Both phases show distinct cleavage, the chloritic variety being slightly less schistose. Both are dark green.

Above the iron-bearing bed, lying on its eroded edges and overlain by glacial drift, are a few feet of dark red fragmental rock. This rock, which is penetrated by the shaft, consists largely of small pebbles or concretions of impure ferruginous and argillaceous material cemented together by siliceous iron oxide. It is believed to be analogous to the ferruginous Cretaceous rock occurring locally in the Mesabi district.

WILCOX MINE

The Wilcox mine, operated by the Paterson Construction Company. is located in the SE¼ of NW¼ of section 13, T. 45N., R. 30W., just south of the village of Woodrow, and about 6 miles north of east from Brainerd. The property embraces also several of the adjoining 40-acre tracts.

The iron-bearing belt on which the mine is situated runs across the northern half of section 13 approximately N.60°E., and dips about 65° south. It consists mainly of ore, but a little ferruginous chert and paint rock are associated with the ore, especially along the borders of the belt.

The iron-bearing rock is bounded both on the north and south by light green and gray slate. The hanging wall slate near the contact of the iron-bearing rock is decomposed, clayey, and of a bluish green color. In some places quartz veins occur in it and at others it is mixed with brown iron-stained clay. Quartz and clay are also found in the ore along the contact.

The portion of the ore bed occurring along the hanging wall usually consists of ocherous yellow limonite, soft but distinctly bedded. This grades into yellowish and brownish black, medium hard limonite, which forms the main ore body.

The foot-wall of the iron-bearing rock is a light-colored, greenish or grayish slate with marked schistosity but with little or no evidence of bedding. Near the ore body the slate becomes dark red, due to impregnation with hematite, and is known as paint rock. It is medium hard and shows cleavage similar to the green and gray slate. Locally traces of bedding are found in it, and at such points the cleavage and bedding appear to be parallel. The contact between the paint rock and ore is usually sharp.

Both the ore and wall rocks contain a soft but compact, fine-textured, decomposed rock, also termed paint rock, which has the appearance of being intrusive. It occurs in masses which, although in general parallel to the strike of the enclosing rocks, are dike-like in character. The rock itself is light green where associated with green or gray slate, and dark red where associated with dark red slate or ore. When wet it is soft and clayey, but on drying it hardens. It does not show any cleavage and has sharp contacts with the enclosing rocks.

The Wilcox shaft is situated north of the iron-bearing belt in the slate which forms the foot-wall of the ore body. It has a depth of 230 feet, of which the upper 95 feet are in glacial drift and the rest in green and gray slate. The main hauling level is at 200 feet, and the principal auxiliary level is at 125 feet. Most of the ore now mined is being taken from the 112-foot level.

The ore, as already mentioned, is in part a yellow or brown, porous, ocherous ore and in part a brownish black, medium hard ore. Both types are limonitic. The following average cargo analysis of the ore is given by the Lake Superior Iron Ore Association.[187]

---

[187] Lake Superior Iron Ore Association, *op. cit.*, p. 11.

Average Cargo Analysis of Ore Dried at 212° F., Expected from the Wilcox Mine for the Season 1917

	Fe	P	SiO_2	Mn	Al_2O_3	CaO	MgO	S	Loss by ignition
Per cent.....	57.40	.25	6.00	.50	2.90	.45	.25	.03	8.70

BRAINERD-CUYUNA MINE

The Brainerd-Cuyuna mine, of the Brainerd-Cuyuna Mining Company, is situated in the southern part of the city of Brainerd in the NE¼ of SW¼ of section 36, T. 45N., R. 31W. The property includes also several of the adjoining 40-acre tracts. The shaft, which is situated northwest of the iron-bearing belt in the foot-wall slate, has a depth of 164 feet, of which the upper 90 feet are in glacial drift. A cross-cut runs southeastward from it through slate into the north ore body at the 154-foot level. At the bottom of the shaft, the slate is light green and gray, but near the ore body it is dark red due to impregnation by hematite. Southeast of the north ore body is the south ore body, separated from it by a thin bed of barren rock.

The ore from the Brainerd-Cuyuna mine is yellowish and brownish limonite typical of the south range. It occurs in two lens-like bodies, the north lens and the south lens. The north lens consists mainly of soft yellow ocherous ore, while the south lens ore is darker and somewhat manganiferous.

The iron-bearing belt has a general trend of about N.50°E. in the vicinity of Brainerd, running from the southeastern part of section 30, T. 45N., R. 30W., through the northwestern corner of section 31 into the northeastern part of section 36, T. 45N., R. 31W., from where it continues southwestward through most of section 36. The bed has a fairly steep southeasterly dip.

BARROWS MINE

The Barrows mine, from which ore was produced during 1913 and 1914 by the Virginia Ore Mining Company, of M. A. Hanna and Company, is situated in the NW¼ of SE¼ of section 10, T. 44N., R. 31W. It is the westernmost of the south range mines that has been operated.

The main hoisting shaft has a total depth of 160 feet, of which the upper 110 feet are in glacial drift and the rest in dark green, massive, finely crystalline diabase which forms the hanging wall of the ore body. The main hauling level was at 160 feet and the upper working level at 120 feet when the mine was in operation.

The ore body has a general strike of about N.40°E., while the dip varies from 65° southeast to vertical. At a few places northwesterly dips are found. The main cross-cut on the 160-foot level runs northwestward from the shaft, cutting through the hanging wall diabase and the ore body into the foot-wall rock which consists of a mixture of iron-bearing rock and ocherous clay. The contact between the ore and hanging wall diabase is very regular in strike but varies in dip between 65° and 85° southeast. The ore body has a width of about 60 feet where the main cross-cut passes through it. The contact between the ore and the foot-wall rock dips about 65° south.

The diabase is a massive, dark green, medium fine-grained rock with distinct ophitic texture. Most of it is hard and appears to be fresh, but some of it, especially that near the contact of the ore is soft and altered. The altered phase still retains the original texture to a large extent, but its color is brownish green and it appears to consist mainly of clay and ocherous hydrated iron oxide with perhaps some chlorite. Even some of the fresh looking rock has suffered considerable alteration to chlorite.

The ore as a rule is finely laminated and varies in color from yellow to dark brown or black. Yellow laminae are interlayered with dark brown laminae, the latter predominating, while in places thin argillaceous reddish or greenish layers occur. Much of the ore is ocherous and has a porous texture, but much of it, although soft, is dense and compact. Layers of dark brown or bluish brown hard ore are interbedded with the soft ore. The bedding as a rule dips steeply to the southeast, but locally northwesterly dips are found. The contact between the ore and the diabase is nearly everywhere sharp and distinct, but the contact with the foot-wall rocks is less so.

The foot-wall rock at the Barrows mine is largely of the variety usually termed paint rock by the miners. Paint rock includes many kinds of soft, argillaceous, iron-stained rocks some of which are massive and some schistose. The paint rock at the Barrows mine is similar to the massive paint rock at the Wilcox mine, and like it appears to be the decomposed phase of a fine-grained igneous rock. As it occurs in the ground it is soft, wet and clayey, but on drying it hardens and becomes dense and compact. It is fine-grained, breaks with even fracture, and varies in color from grayish green, to ocherous yellow, brown, or dark red, depending on the degree of oxidation and hydration. The first change appears to be one of oxidation from the green ferrous form to the dark red ferric form. The latter then becomes hydrated and turns brown and yellow. Most of the rock is even colored throughout, but some shows lamination due to color banding. The foot-wall paint rock occurs as a layer about 30 feet thick where penetrated by the main cross-cut. Beyond it to the northwest are interbedded iron-bearing rock and paint rock. The layering of the iron-bearing beds usually dips steeply to the southeast, but the contacts between iron-bearing rock and paint rock are more irregular.

The original nature of the paint rock is difficult to determine. Its general appearance is that of a decomposed igneous rock, yet it is not unlike a decomposed, dense, homogeneous slate. Its general parallelism in layering with the iron-bearing rock suggests that the two rocks were laid down at approximately the same time. However, the minor irregularities along the contacts indicate that there was not continuous deposition. In general it seems more probable that the paint rock is of igneous origin, representing either contemporaneous volcanic flows or later intrusive sheets.

BIBLIOGRAPHY OF EAST CENTRAL MINNESOTA AND THE CUYUNA IRON-ORE DISTRICT

Adams, F. S. The iron formation of the Cuyuna range: *Econ. Geology,* vol. 5, pp. 729-40, 1910; vol. 6, pp. 60-70 and 156-80, 1911.

Anon. A difficult shaft sinking operation at Deerwood, Minn.: *Iron Tr. Rev.,* vol. 43, pp. 772-74, Nov. 5, 1908.

——— The Cuyuna range, Minnesota: *Eng. and Min. Jour.,* vol. 90, p. 1214, Dec. 17, 1910.

——— Cuyuna range development: *Eng. and Min. Jour.,* vol. 91, p. 1146, June 10, 1911.

——— Cuyuna's first ore shipment: *Min. Wld.,* vol. 34, p. 1187, June 10, 1911.

——— Cuyuna range notes: *Eng. and Min. Jour.,* vol. 92, p. 304, Aug. 12, 1911.

——— Heavy movement from Hill ore lands: *Iron Tr. Rev.,* vol. 50, pp. 562-65, Mar. 7, 1912.

——— Cuyuna iron range: *Eng. and Min. Jour.,* vol. 93, p. 1025, May 25, 1912.

——— Iron-ore railroads at Lake Superior: *Eng. and Min. Jour.,* vol. 93, p. 1188, June 15, 1912.

——— Cuyuna iron ores: *Eng. and Min. Jour.,* vol. 93, p. 1284, June 29, 1912.

——— First Cuyuna range stripping: *Iron Tr. Rev.,* vol. 51, p. 1177, Dec. 19, 1912.

——— The Cuyuna iron range: *Eng. and Min. Jour.,* vol. 94, pp. 97-98, July 20, 1912.

——— Sinking a concrete shaft lining through quicksand: *Eng. Rec.,* vol. 67, pp. 383-84, April 5, 1913.

——— Handling ore from the Cuyuna range: *Iron Tr. Rev.,* vol. 53, pp. 729-33, Oct. 23, 1913.

——— Duluth, Minnesota: (Special correspondence on the Minnesota iron ranges). *Min. and Sci. Press,* vol. 108, p. 190 (Jan. 24), p. 469 (Mar. 14), p. 667 (Apr. 18), p. 1026 (June 20), 1914.

——— The truth about the Cuyuna: *Iron Tr. Rev.,* vol. 55, p. 972, Nov. 26, 1914.

——— Quietus on speculators is placed by Minnesota Tax Commission, which develops the facts about the iron ore deposits of the Cuyuna range: *Iron Tr. Rev.,* vol. 55, p. 985, Nov. 26, 1914.

——— Lake Superior iron ranges: *Eng. and Min. Jour.,* vol. 99, pp. 73-76, Jan. 9, 1915.

——— Stripping the Pennington mine: *Excav. Eng.,* vol. 11, pp. 175-76, Feb. 19, 1915.

——— Increased activity on the Cuyuna: *Iron Tr. Rev.,* vol. 57, p. 191, July 22, 1915.

——— Good results follow careful work. South range on the Cuyuna promises to be lively district: *Iron Tr. Rev.,* vol. 57, pp. 363-64, Aug. 19, 1915.

——— Cuyuna range tonnage for 1915: *Eng. and Min. Jour.,* vol. 100, p. 403, Sept. 4, 1915.

——— Electrical power for the Cuyuna range: *Eng. and Min. Jour.,* vol. 100, pp. 403-4, Sept. 4, 1915.

——— The Dean-Itasca and Pennington mines: *Iron Tr. Rev.,* vol. 57, pp. 1140-41, Dec. 9, 1915.

——— Armour mines on Cuyuna range: *Iron Tr. Rev.,* vol. 57, pp. 1223-24, Dec. 23, 1915.

Anon. Stripping the Hillcrest mine with a sand pump: *Eng. and Min. Jour.*, vol. 101, pp. 211-15, Jan. 29, 1916.

——— Welfare work on the Cuyuna range: *Iron Tr. Rev.*, vol. 58, p. 450, Feb. 24, 1916.

——— Method of drop-shaft sinking on Cuyuna range: *Eng. and Min. Jour.*, vol. 101, p. 404, Feb. 26, 1916.

——— The Rowe mine ore-washing plant, Minnesota: *Min. Wld.*, vol. 44, pp. 517-19, Mar. 11, 1916.

——— Predicted troubles not realized at the Adams mine on the Cuyuna: *Iron Tr. Rev.*, vol. 58, p. 1284, June 8, 1916.

Appleby, W. R., and Newton, E. Preliminary concentration tests on Cuyuna ores: *Univ. of Minn. School of Mines Exp. Sta. Bull.* No. 3, 1915.

Barr, J. C. Chain grizzly at the Rowe mine: *Eng. and Min. Jour.*, vol. 101, pp. 599-600, Apr. 1, 1916.

Barrows, W. A., Jr. The Cuyuna district, South range, iron ores: *Iron Tr. Rev.*, vol. 51, pp. 923-24, Nov. 14, 1912.

(See also Zapffe, Carl, and Barrows, W. A., Jr.)

Berkey, C. P. Geology of the St. Croix dalles: *Amer. Geol.*, vol. 20, pp. 345-83, 1897; vol. 21, pp. 139-55 and 270-94, 1898.

Bradt, H. H. (See Newton, E., and Bradt, H. H.)

Burchard, E. F. Iron ore, pig iron, and steel: *Min. Res. U. S., U. S. Geol. Survey.* Reports for 1911, 1912, 1913, 1914, 1915, and 1916.

Cheney, C. A., Jr. Structure of the Cuyuna iron-ore district of Minnesota: *Eng. and Min. Jour.*, vol. 99, pp. 1113-15, June 26, 1915.

Crowell and Murray. The iron ores of Lake Superior: pp. 159-61, 1914.

——— The iron ores of Lake Superior: pp. 201-212, 1917.

Croze, W. W. J. Minnesota's great iron-mining industry: *Min. Wld.*, vol. 33, pp. 717-21, Oct. 15, 1910.

Donovan, P. W. Churn drill angle holes on the Cuyuna: *Eng. and Min. Jour.*, vol. 96, pp. 1117-18, Dec. 13, 1913.

——— Some aspects of exploration and drilling on the Cuyuna range: *Proc. Lake Sup. Min. Inst.*, vol. 20, pp. 136-41, Sept. meeting, 1915. Also *Iron Tr. Rev.*, vol. 57, p. 534, 1915.

Edwards, G. E. Rapid development of the Cuyuna range: *Min. Wld.*, vol. 39, pp. 339-41, Aug. 23, 1913.

——— Mining activity on the iron ranges: *Min. Wld.*, vol. 43, pp. 353-60, Sept. 4, 1915.

Emmons, W. H. Outline of the geology of the iron ranges. In Iron mining in Minnesota, by C. E. van Barneveld, *Univ. of Minn. School of Mines Exp. Sta. Bull.*, No. 1, pp. 12-23, 1912.

Estep, H. C. Independents are conspicuous. A review of interesting developments of the past year on the Minnesota iron ranges: *Iron Tr. Rev.*, vol. 56, pp. 73-81, Jan. 7, 1915.

——— Iron range developments in 1915: *Iron Tr. Rev.*, vol. 58, pp. 81-92, Jan. 6, 1916.

Gregory, W. Bibliography of Minnesota mining and geology: *Univ. of Minn. School of Mines Exp. Sta. Bull.* No. 4, pp. 105-6, 1915.

Grout, F. F. Contribution to the petrography of the Keweenawan: *Jour. Geology*, vol. 18, pp. 633-57, 1910.

Hall, C. W. Keweenawan area of eastern Minnesota: *Bull. Geol. Soc. Amer.*, vol. 12, pp. 313-42, 1901.

——— Keewatin area of eastern and central Minnesota: *Bull. Geol. Soc. Amer.*, vol. 12, pp. 343-76, 1901.

HARDER, E. C. Manganese deposits of the United States with sections on foreign deposits, chemistry, and uses: *U. S. Geol. Survey Bull.* 427, pp. 130-31, 1910.

——— Manganiferous iron ores of the Cuyuna district, Minnesota: *Amer. Inst. Min. Eng. Bull.*, Sept. 1917.

——— Manganiferous iron ores: *U. S. Geol. Survey Bull.* 666-EE, 1917.

——— and JOHNSTON, A. W. Notes on the geology and iron ores of the Cuyuna district, Minnesota: *U. S. Geol. Survey Bull.* 660-A, 1917.

HEWETT, D. F. Manganese and manganiferous ores: *Min. Res. U. S., U. S. Geol. Survey, Reports* for 1913, 1914, 1915, and 1916.

HURD, RUKARD. Iron ore manual of the Lake Superior district, pp. 41-42, and 75-77, 1911.

IRVING, R. D. The geological structure of northern Wisconsin: *Wis. Geol. and Nat. Hist. Survey, Geol. of Wis.*, vol. 3, 1873-1879, p. 18, 1880.

——— The copper-bearing rocks of Lake Superior: *U. S. Geol. Survey Third Ann. Rept.*, p. 162 and Pl. III, 1883.

——— Preliminary paper on an investigation of the Archean formations of the northwestern states: *U. S. Geol. Survey Fifth Ann. Rept.*, pp. 196-97 and Pl. 22, 1885.

——— Classification of early Cambrian and pre-Cambrian formations: *U. S. Geol. Survey Seventh Ann. Rept.*, pp. 417-23 and Pl. 41, 1888.

KELLOGG, L. O. Notes on the Cuyuna range: *Eng. and Min. Jour.*, vol. 96, pp. 1199-1203, Dec. 27, 1913; vol. 97, pp. 7-10, Jan. 3, 1914.

——— Lake Superior iron ranges: *Eng. and Min. Jour.*, vol. 97, pp. 83-86, Jan. 10, 1914.

——— Stripping with the hydraulic giant: *Eng. and Min. Jour.*, vol. 97, pp. 166-67, Jan. 17, 1914.

——— Stripping the overburden in open pit mining: *Eng. Mag.*, vol. 50, pp. 896-909, Mar. 1916.

KLOOS, J. H. Geological notes on Minnesota: *Geol. and Nat. Hist. Survey of Minn. Tenth Ann. Rept.*, pp. 175-200, 1881. Also *Zeitschr. d. Deutsch. Geol. Gesell.*, p. 417, 1880.

(See also STRENG, A., and KLOOS, J. H.)

JOHNSTON, A. W. (See HARDER, E. C., and JOHNSTON, A. W.)

Lake Superior Iron Ore Association. Analyses of Lake Superior iron ores: *Yearbooks* for seasons 1911-1917.

LEITH, C. K. A summary of Lake Superior geology with special reference to the recent studies of the iron-bearing series: *Trans. Amer. Inst. Min. Eng.*, vol. 36, pp. 116 and 149-50, 1906.

——— Geology of the Cuyuna iron range, Minnesota: *Econ. Geology*, vol. 2, pp. 145-52, 1907.

(See also VAN HISE, C. R., and LEITH, C. K.)

MCAULIFFE, P. J. Stripping a mine by hydraulic methods: *Coal Age*, vol. 5, pp. 568-69, Apr. 4, 1914.

MCCARTY, E. P. Hydraulic stripping at Rowe and Hillcrest mines on the Cuyuna range, Minnesota: *Proc. Lake Sup. Min. Inst.*, vol. 20, pp. 162-73, Sept. meeting, 1915.

——— Manganiferous iron ores of the Cuyuna range: *Eng. and Min. Jour.*, vol. 100, pp. 400-2, Sept. 4, 1915.

McCarty, E. P. Hydraulic stripping on Cuyuna: *Iron Tr. Rev.*, vol. 58, pp. 135-39, Jan. 13, 1916.

Minnesota Bureau of Labor. Reports of mine inspectors, *14th Biennial Rept.*, pp. 145 et seq., 1913-1914.

Minnesota Tax Commission

First Biennial Rept., 1908, pp. 110 et seq.

Second Biennial Rept., 1910, pp. 49 et seq.

Third Biennial Rept., 1912, pp. 58 et seq.

Fourth Biennial Rept., 1914, pp. 75 et seq.

Fifth Biennial Rept., 1916, pp. 73 et seq.

Neimeyer, C. The Cuyuna iron range: *Eng. and Min. Jour.*, vol. 91, p. 797, Apr. 22, 1911.

Newton, E. Concentration of Cuyuna ores: *Proc. Lake Sup. Min. Inst.*, vol. 20, pp. 200-12, Sept. meeting, 1915.

——— Manganiferous iron ores of the Cuyuna district: *Univ. of Minn. School of Mines Exp. Sta. Bull.* 5, 1918.

——— and Bradt, H. H. Beneficiation of Lake Superior ores. In iron ore, pig iron, and steel, by E. F. Burchard: *Min. Res. U. S.*, 1915, *U. S. Geol. Survey* 1916.

(See also Appleby, W. R., and Newton, E.)

Rotthaus, J. E. Magnetic surveying on the Cuyuna: *Eng. and Min. Jour.*, vol. 98, pp. 603-4, Oct. 3, 1914.

Sawhill, R. V. 1915 Lake Superior ore shipments: *Iron Tr. Rev.*, vol. 58, pp. 602-5, Mar. 16, 1916.

——— 1916 Lake Superior ore shipments: *Iron Tr. Rev.*, vol. 60, pp. 535-37, Mar. 1, 1917.

Spurr, J. E. The stratigraphic position of the Thomson slates: *Amer. Jour. Sci.*, 3d ser., vol. 148, pp. 159-66, 1894.

Streng, A., and Kloos, J. H. The crystalline rocks of Minnesota: *Geol. and Nat. Hist. Survey of Minn. Eleventh Ann. Rept.*, pp. 30-85, 1882. Also *Neues Jahrb. f. Min. u. Petrifactenkunde*, p. 36, 1877.

Swanson, August. Annual report of Inspector of Mines, Crow Wing County, 1st, 2d, and 3d reports, June 1913, June 1914, and June 1915.

Sweet, E. T. Geology of the western Lake Superior region: *Wis. Geol. and Nat. Hist. Survey, Geol. of Wis.*, vol. 3, 1873-1879, pp. 334 et seq., 1880.

Thomas, Kirby. Notes on the geology of a new iron district in Minnesota: *Mines and Minerals*, vol. 25, p. 27, Aug. 1904.

——— A new, promising Lake Superior iron district: *Min. Wld.*, vol. 21, pp. 446-48, Nov. 5, 1904.

——— Non-Bessemer ore will probably be principal product of the Cuyuna range: *Iron Tr. Rev.*, vol. 50, p. 1178, May 30, 1912.

——— The Cuyuna iron range: *Min. and Sci. Press*, vol. 105, pp. 52-53, July 13, 1912.

Thwaites, F. T. Sandstones of the Wisconsin coast of Lake Superior: *Wis. Geol. and Nat. Hist. Survey Bull.* 25, 1912.

Upham, Warren. Notes of rock outcrops in central Minnesota: *Geol. and Nat. Hist. Survey of Minn. Eleventh Ann. Rept.*, pp. 86-136, and 220, 1884.

——— Preliminary report of field work during 1893 in northeastern Minnesota, chiefly relating to glacial drift: *Geol. and Nat. Hist. Survey of Minn. Twenty-second Ann. Rept.*, pp. 26-29, 1894.

——— Geology of Benton, Sherburne, Stearns, Todd, Wadena, Crow Wing, Morrison, Mille Lacs, Kanabec, and Pine counties: *Geol. and Nat. Hist. Survey of Minn., Geol. of Minn.*, vol. 2, 1882-1885, pp. 426-70 and 562-645, 1888.

——— Geology of Aitkin, Cass, and Crow Wing counties: *Geol. and Nat. Hist. Survey of Minn., Geol. of Minn.*, vol. 4, 1896-1898, pp. 25-81, 1899.

Van Barneveld, C. E. Iron mining in Minnesota: *Univ. of Minn. School of Mines Exp. Sta. Bull.* 1, pp. 205-7, 1912.

Van Hise, C. R. Correlation papers: Archean and Algonkian: *U. S. Geol. Survey Bull.* 86, pp. 51-208, 1892.

——— and Leith, C. K., Pre-Cambrian geology of North America: *U. S. Geol. Survey Bull.* 360, pp. 108-402, 1909.

——— The geology of the Lake Superior region: *U. S. Geol. Survey Mon.* 52, pp. 211-24 (Chap. IX, Cuyuna district, etc., Carl Zapffe, joint author), 1911.

Winchell, N. H. Note on the age of the rocks of the Mesabi and Vermilion iron districts: *Geol. and Nat. Hist. Survey of Minn. Eleventh Ann. Rept.*, pp. 168-70, 1882.

——— The crystalline rocks of the northwest: *Geol. and Nat. Hist. Survey of Minn. Thirteenth Ann. Rept.*, pp. 124-40, 1884. Also *Proc. Amer. Assn. Adv. Sci.*, 33d meeting, pp. 366-79, Sept. 1884.

——— The crystalline rocks of Minnesota: *Geol. and Nat. Hist. Survey of Minn. Thirteenth Ann. Rept.*, pp. 36-38, 1884.

——— The crystalline rocks of Minnesota: *Geol. and Nat. Hist. Survey of Minn. Seventeenth Ann. Rept.*, pp. 5-74, 1888.

——— The crystalline rocks: *Geol. and Nat. Hist. Survey of Minn. Twentieth Ann. Rept.*, pp. 1-28, 1891.

——— The pre-Silurian rocks of Minnesota: *Geol. and Nat. Hist. Survey of Minn. Twenty-first Ann. Rept.*, Table opposite p. 4, 1892.

——— The geology of Carlton and southern St. Louis counties: *Geol. and Nat. Hist. Survey of Minn., Geol. of Minn.*, vol. 4, 1896-1898, pp. 1-24 and 212-21, 1899.

——— Geological map of Minnesota: *Geol. and Nat. Hist. Survey of Minn., Geol. of Minn.*, vol. 6, 1900-1901, Frontispiece, 1901.

——— The Cuyunà iron range: *Econ. Geology*, vol. 2, pp. 565-70, 1907.

Woodbridge, D. E. Electric power in Mesaba mining: *Iron Age*, vol. 75, pp. 2069-70, June 29, 1905.

——— Iron ore in Crow Wing County, Minn.: *Eng. and Min. Jour.*, vol. 84, pp. 775-76, Oct. 26, 1907.

——— Lake Superior iron mines in 1907: *Eng. and Min. Jour.*, vol. 85, p. 114, Jan. 11, 1908.

——— Notes from the Lake Superior iron ranges: *Eng. and Min. Jour.*, vol. 89, pp. 863-64, Apr. 23, 1910.

——— The Lake Superior iron country: *Eng. and Min. Jour.*, vol. 91, p. 31, Jan. 7, 1911.

——— Iron ore in Lake Superior district: *Eng. and Min. Jour.*, vol. 93, p. 31, Jan. 6, 1912.

——— The Lake Superior iron-ore district: *Eng. and Min. Jour.*, vol. 95, p. 85, Jan. 11, 1913.

——— Changes and outlook in the Lake iron-ore trade: *Iron Age*, vol. 93, pp. 15-18, Jan. 1, 1914.

Zapffe, Carl. The geology of the Cuyuna iron-ore district. Unpublished thesis, Univ. of Wis., 1907.

——— The Cuyuna iron-ore district of Minnesota: *Brainerd Tribune, Supplement*, Sept. 2, 1910.

——— Geology of Cuyuna iron-ore district, Minnesota: *Min. Wld.*, vol. 34, pp. 585-88, Mar. 18, 1911.

——— Geology of the Cuyuna iron-ore district, Minnesota: *Science*, n. s., vol. 33, p. 463, Mar. 24, 1911.

——— The Cuyuna iron range: *Eng. and Min. Jour.*, vol. 91, p. 993, May 20, 1911.

——— South range of the Cuyuna district: *Brainerd Daily and Weekly Dispatch Supplement*, Jan. 19, 1912.

——— A survey of the developments and operations in the Cuyuna iron-ore district of Minnesota: *Proc. Lake Sup. Min. Inst.*, vol. 20, pp. 125-35, Sept. meeting, 1915.

——— Matters of interest to operators regarding the Cuyuna district: *Proc. Lake Sup. Min. Inst.*, vol. 20, pp. 191-99, Sept. meeting, 1915.

——— Development of the Cuyuna range: *Iron Tr. Rev.*, vol. 57, pp. 1131-33 and 1154b, Dec. 9, 1915.

——— and Barrows, W. A., Jr. The iron ores of the South range of the Cuyuna district, Minnesota: *Trans. Amer. Inst. Min. Eng.*, vol. 44, pp. 3-13, 1912. Abstract, *Iron. Tr. Rev.*, vol. 51, p. 881, Nov. 7, 1912.

(See also Van Hise, C. R., and Leith, C. K.)

INDEX

Page

Adams, Cuyler.......... 97
  work of.......... 97
Adams, F. S., work of.......... 99
Adams mine.......... 104
  analysis of ore from.......... 120
  geology of.......... 162
  production of.......... 108
Agawa formation, nature of.......... 11
Aitkin County, rock outcrops in.....45, 52, 64
Algoma mine.......... 102
  geology of.......... 137
  production of.......... 108
Altitudes 95
Amphibole, occurrence of.......... 60
Amphibole-magnetite rocks, analysis of.... 126
  composition of..........4, 117
  correlation of.......... 117
Animikie group, distribution and character of..........11, 109, 123
Ann River, granite outcrops near.......... 43
Archean system, rocks of.......... 10
Argillite, term defined..........3, 4
Armour No. 1 mine.......... 100
  geology of.......... 144
  production of.......... 108
Armour No. 2 mine.......... 101
  geology of.......... 146
  production of.......... 108
Atkinson, outcrops near.......... 83
Barnum, outcrops near.......... 76
Barrows mine.......... 102
  production of.......... 108
Bayfield group, correlation of.......... 13
Benton County, rock outcrops in....38, 40, 63
Berkey, C. P., referred to.......... 28
Biwabik formation, distribution and character 12
Black Hoof River, rock outcrops near.... 85
Blackhoof Lake, analysis of ore from.... 120
Bowles, Oliver, referred to.......... 39
Bradbury Brook, granite outcrops near.... 41
Bradt, H. H., acknowledgments to....155, 156
Brainerd-Cuyuna mine.......... 105
  geology of.......... 166
  production of.......... 108
Brainerd Mining Company.......... 103
Brookston, slate near.......... 90
Cambrian system, rocks assigned to......9, 91
Canadian-Cuyuna Iron Mining Company.. 105
Carbonate rock, analyses of.......... 120
  occurrence and character of........3, 116
  relation to iron ore deposits.......... 130
Carlton, rock outcrops near.......... 90
Carlton County, rock outcrops in..54, 67, 75, 92
Cass County, granite outcrops in........30, 31
Cheney, C. A., referred to.......... 114
Chert, distribution and character of...... 115
  nature of.......... 3
Chlorite, occurrence of.......... 60
Chloritic schist, analysis of.......... 120
  distribution and character of......58, 110
  occurrence of.......... 114
  origin of..........119, 122
Clements, J. M., referred to..........10, 21
Cloquet, rock outcrops near.......... 90
Coldspring, rock outcrops near.......... 39
Concentrating plant at Rowe mine....... 104
Cowan Brook, granite outcrops near...... 44
Cretaceous rocks, distribution and character of....14, 30, 93, 94, 110, 124
  nature of.......... 8
Croft mine.......... 107
  geology of.......... 150
  production of.......... 108
Crow Wing County, iron ore in.......... 125
  limestone in.......... 63
Cowan Brook, granite outcrops near...... 44
Cuyuna district, area of.......... 95
  geology of.......... 107
  history of.......... 96
  location of.......... 94
Cuyuna-Mille Lacs mine.......... 102
  geology of.......... 152
  jasper in.......... 118
  production of.......... 108
Dam Lake, quartzite outcrops near.....52, 64
Deerwood members, structure of.......... 114
Denham, rock outcrops near..........47, 65
Drainage 95
Duluth-Brainerd Iron Company.......... 105
Feigh property.......... 142
Ferguson, H. G., work of....135, 137, 141, 157
Ferro mine.......... 105
  geology of.......... 135
  production of.......... 108
Ferruginous chert, analyses of.......... 120
  nature of..........115, 129
  term defined.......... 3
Ferruginous slate, analyses of.......... 120
  distribution and character of.......... 116
  nature of.......... 3
Fishtrap Creek, rock outcrops near....... 49
Folding, extent of.......... 111
Freedham, granite outcrops near.......... 32
Fuller, M. L., work of..........5, 8, 9, 14
Garnet, occurrence of..........60, 62
Geological investigation, previous.......... 15
Giants Range granite, correlation of....30, 31
Gillespie Brook, rock outcrops near...... 69
Glacial deposits, distribution and character of..........5, 107
Gneiss, distribution and character of...... 46
Granite, distribution and character of..... 30
Granite City, granite outcrops near...... 35
Grant, U. S., referred to..........6, 21
Gravelville, granite outcrops near........ 33

Page
Greenstone, distribution and character of.. 10
Grout, F. F., referred to.....13, 28, 39, 42, 58
Hall, C. W. referred to.................
.....5, 8, 9, 14, 23, 28, 29, 63, 93
Hanna, M. A., and Company..........98, 166
Harrington, M. W., referred to.......... 5
Hay Creek, granite outcrops near........ 44
Hematite, distribution and character of..
...............133, 143, 147, 161
Hematitic chert, distribution and character of..................... 115
  nature of.......................... 3
Hematitic schist, analysis of............. 120
  occurrence of...................... 119
  origin of.......................... 4
Hematitic slates, analysis of............. 100
  distribution and character of......... 115
  nature of.......................... 3
Hill Mines Company.................107, 141
Hillcrest mine........................ 106
  geology of......................... 141
  production of...................... 108
Hillman Creek, granite outcrops near..34, 36, 37
Hinckley sandstone, distribution and character of.................... 92
  explanation of term................. 91
History of district...................... 96
Hobart exploration shaft................ 163
Hobart Iron Company.................98, 163
Hoch mine............................ 102
Hopkins mine, geology of................ 157
Hornblende schist, distribution and character of.................66, 72
Huronian series, distribution and character of.....................11, 16
Huronian, upper. *See* Animikie
Hydraulic stripping at Rowe mine........ 103
Igneous rocks, lithology of.............. 112
  silicic, outcrops of.................. 30
  subsilicic, outcrops of.............. 49
Inland Steel Company..98, 100, 101, 144, 146, 148
Intrusive rocks, distribution and character of....................10, 123
  See also Igneous rocks
Iron-bearing formation, analysis of specimens of.................. 120
  association of, with igneous rocks.... 119
  composition of..................... 113
  deposition of...................... 130
  distribution and character of......114, 118, 124, 140, 159, 163, 164, 165
  horizons of........................ 113
  term defined....................... 3
  See also particular formations
Iron carbonate rock. *See* Carbonate rock
Iron Mountain mine..................... 102
Iron Mountain Mining Company......... 102
Iron ores, occurrence and character of....
..................118, 129, 132
  origin of.......................... 130
  production of...................107, 108
  relation to adjacent rocks........... 132

Page
Ironton mine.......................... 102
  geology of......................... 146
  production of...................... 108
Iroquois Iron Company.............100, 101
Irving, R. D., referred to...............15, 16
Jaspilite, definition of.................. 3
  distribution and character of......... 118
Joan mine, geology of................... 157
Joan No. 3 mine, geology of............ 137
Jones and Laughlin Steel Company...... 98
Kanabec County, granite outcrops in...... 43
  sandstone in....................... 91
Keeweenawan series, correlation of....... 110
  distribution and character of........
................13, 93, 110, 124
  folding in......................... 111
  intrusions of...................... 123
  sediments in....................... 13
Kellogg, L. O., referred to.............. 96
Kennedy mine......................99, 100
  analyses of rock from.............. 120
  geology of......................... 159
  production of...................... 108
Kettle Lake, slate near.................. 68
Kettle River, rock outcrops near........56, 68
  sandstone near..................... 91
Knife Lake slate, distribution and character of..................... 11
Lake Emily, iron bearing rocks near...... 125
Lake Superior Iron Ore Association. Analyses of Lake Superior iron ores. Quoted......137, 138, 142, 144, 145, 146, 148, 149, 150, 151, 153, 156, 158, 162, 165
Lang, W. B., acknowledgments to........ 2
Lawson, A. C., referred to.............. 18
Ledoux, rock outcrops near.............. 61
Leech Lake, granite outcrops near........ 31
Leith, C. K., referred to...............
.......6, 10, 13, 21, 22, 24, 25, 31, 53, 63, 109, 111, 124, 129
Limestone, distribution and character of.. 66
Limonite, distribution and character of.... 134
Limonitic chert, distribution and character of..................... 115
  nature of.......................... 3
Limonitic slates, distribution and character of..................... 115
  nature of.......................... 3
Little Elk River, rock outcrops near...... 59
Little Falls, rock outcrops near..........
...............27, 32, 50, 60, 61
Long Lake, rock outcrops near........... 52
McAuliffe, P. J., referred to............ 103
McCarthy, J. H., analyses by............ 120
McCarty, E. P., referred to............. 103
McGrath, rock outcrops near............ 46
Magnetic surveys....................... 97
Magnetitic slates, composition of........3, 117
  correlation of...................... 117

Page

- Mahnomen mine........................ 106
  - geology of......................153, 157
  - production of...................... 108
- Mahtowa, outcrops near.................77, 79
- Malloy dam, granite outcrop near....... 46
- Mangan No. 1 mine...................... 106
  - geology of.......................... 154
  - production of...................... 108
- Mangan No. 2 mine...................... 106
  - analyses of rock from............... 120
  - geology of.......................... 159
  - production of...................... 108
- Manganese ore, occurrence of........... 134
- Manganiferous ore, distribution and character of....118, 125, 135, 156, 158
  - nature of......................119, 134
  - production of...................107, 108
- Manitou eruptives...................... 93
- Meacham mine 107
  - geology of.......................... 150
  - production of...................... 108
- Meinzer, O. E., referred to........5, 8, 9, 14
- Melrose, rock outcrops near............ 31
- Merrimac Mining Company................ 107
- Mesabi district, geology of............ 11
  - geological report on................20, 21
- Metamorphic rocks, outcrops of......... 58
- Metamorphism, effects of.............63, 124
- Meyer's quarry......................... 34
- Mica schist, distribution and character of.. 67
- Michalski, William, rock outcrop on land of 56
- Mill Island, rock outcrops on.......... 60
- Mille Lacs County, granite outcrops in.... 40
- Mille Lacs Mine. *See* Cuyuna-Mille Lacs mine
- Minneapolis, St. Paul, and Sault Ste. Marie Railroad. Cuyuna Range Branch 96, 100
- Minnesota, east central, sequence of rocks in 24
- Minnesota, northeastern, sequence of rocks in 6
- Minnesota, southern, sequence of rocks in 5
- Minnesota Geological and Natural History Survey, early investigations of 18
  - rock classification used by............ 19
- Minnesota University. School of Mines Experiment Station, analyses made by 119
- Moose Horn River, rock outcrop near.... 76
- Moose Lake, rock outcrops near.......... 75
- Moose River, rock outcrops near......... 79
- Morrison County, chloritic schists in..... 58
  - iron-bearing formation in........125, 128
  - rock outcrops in..................32, 50
- Muscovite, occurrence of................ 66
- Newton, Edmund, acknowledgments to..155, 156
- Northern Pacific Railroad. Duluth-Brainerd branch 96
- Ogelbay, Norton and Company.......... 98
- Ogishke conglomerate, distribution and character of............... 10
- Oliver Mining Company................98, 99
- Onahman Iron Company.............106, 135
- Onamia, granite outcrops near.........40, 42
- Ore analyses
  - Algoma mine 138
  - Armour No. 1 mine.................. 145
  - Armour No. 2 mine.................. 148
  - Croft mine 151
  - Cuyuna-Mille Lacs mine............. 154
  - Ferro mine......................... 137
  - Hillcrest mine 142
  - Ironton mine....................... 146
  - Kennedy mine 162
  - Mahnomen mine 159
  - Meacham mine 150
  - Pennington mine 144
  - Sultana mine 156
  - Thompson mine 149
  - Wilcox mine 166
- Otter Creek, rock outcrops near.......... 87
- Ottrelite, occurrence of.................. 60
- Paint rock, distribution and character of 165, 167
  - nature of.......................... 168
- Paleozoic rocks, distribution and character of 14
- Paragenesis of garnetiferous and staurolitic schist 63
- Park Lake, rock outcrops near........... 81
- Park Lake River, rock outcrops near....57, 78
- Paterson Construction Company......105, 164
- Pennington mine 101
  - geology of.......................... 142
  - production of...................... 108
- Peterson, J. P., slate on land of.......... 80
- Pevon, L., diabase outcrop on land of.... 54
- Phyllite, definition of................... 4
  - distribution and character of........59, 72
- Pickands, Mather and Company.......98, 163
- Pierz, granite outcrops near............. 34
- Pine County, rock outcrops in.....47, 57, 65
  - sandstone in 91
- Pine River, rock outcrops near........... 47
- Pittsburgh Steel Ore Company......103, 139
- Potsdam sandstone 91
- Puckwunge conglomerate 93
- Pyrite, distribution and character of..... 78
- Quartzite, distribution and character of..66, 122
- Quartzitic mica schist, distribution and character of................ 65
- Randall, chloritic schists near............ 59
- Ravicz, L. G., acknowledgments to...... 2
- Red clastic series, correlation of........ 9
  - distribution and character of........ 9
- Rocks, age of.......................... 109
  - classification used by Minnesota and United States surveys compared 18
  - distribution and character of........ 23
  - sequence of......................5, 6, 17
- Rockville, granite outcrops near.......... 39

Page

- Rogers-Brown Ore Company..99, 101, 104, 159
- Rowe mine 103
  - analysis of ore from............... 120
  - concentration plant at............. 104
  - geology of.......................... 139
  - production of...................... 108
- Rucker, granite outcrops near........... 35
- Rum River, granite outcrops near......40, 42
- Saint Cloud, granite outcrops near....... 39
- St. Croix River, lava near............... 28
  - rock outcrops near.............13, 14, 30
  - sandstone near 92
- St. Croix sandstone, distribution and character of 29
  - explanation of term as used by the Minnesota geologists 92
- Saint Francis River, granite outcrops near 40
- St. Louis River, rock outcrops near...... ....57, 88, 91, 92
- St. Louis slate, correlation of..........16, 20
- Sandstone, distribution and character of.. 90
- Sauk Center, rock outcrops near......... 31
- Sauk Rapids, granite outcrops near...... 38
- Savage, John A., and Company......107, 150
- Schultz, A. R., referred to.............. 5
- Sherburne County, granite outcrops in.... 39
- Silicic igneous rocks, distribution and character of.................... 30
- Silver Creek, rock outcrop near.......... 69
- Sioux quartzite, correlation of........... 9
  - distribution and character of........ 8
- Skunk River, granite outcrops near...... 34
- Slate, distribution and character of..59, 60, 110
  - use of term explained.............. 3
- Sluicing at Rowe mine................. 103
- Snake River, granite outcrops near....... 43
  - sandstone near 91
- Split Rock River, rock outcrops near....67, 73
- Spurr, J. E., referred to........20, 21, 22, 90
- Staples, granite outcrops near............ 30
- Staurolite, occurrence of................ 62
- Stearns County, clay deposits in......... 94
  - rock outcrops in.................31, 38
- Structure, development of.............. 111
- Subsilicic igneous rocks, distribution and character of 49
- Sultana mine 104
  - analyses of rock from............... 120
  - geology of........................ 154
  - production of..................... 108

Page

- Swan River, rock outcrops near.......... 61
- Swanson, August, referred to..101, 102, 105, 106
- Sweet, E. T., referred to............... 15
- Sweetman, E. A., acknowledgments to.... 2
- Taylor's Falls, geology near.............. 14
- Terminology 2
- Thomas, Kirby, referred to........97, 98, 103
- Thompson, diabase outcrop near.......... 89
- Thompson mine 101
  - analysis of rock from............... 120
  - geology of........................ 148
  - production of..................... 108
- Thwaites, F. T., referred to.......6, 9, 13, 23
- Tod-Stambaugh Company.............98, 142
- Todd, J. E., referred to................. 6
- Todd County, rock outcrops in..........31, 49
- Topography 95
- Torah (Richmond), clay near............ 94
  - rock outcrops near................. 39
- United States Geological Survey, coöperation of..................... 1
  - investigations by.................. 15
- Upham, Warren, referred to............ 5, 6, 9, 18, 23, 29, 31, 35, 36, 39, 40, 42, 43, 61, 64, 91, 92, 94
- Van Hise, C. R., referred to............ ....6, 10, 13, 17, 20, 22, 24, 25, 31, 53, 63, 109, 111, 124, 129
- Vermilion district, geological report on.... 21
- Virginia Ore Mining Company.......103, 166
- Virginia slate, correlation of............ 28
  - distribution and character of..12, 109, 112
- Wahkon, granite outcrops near........... 42
- Warman, granite quarry at............. 43
- Watab, granite outcrops near............ 38
- Weidman, S., referred to............... 5
- White Fish Lake, limestone reported near 63
- Wilcox mine.......................... 105
  - geology of........................ 164
  - production of..................... 108
- Williams' quarry....................... 50
- Willow River, sandstone near............ 91
- Winchell, N. H., referred to......5, 6, 9, 18, 21, 25, 29, 53, 64, 69, 92, 93
- Wisconsin, sequence of rocks in.......... 5, 6
- Wolff, J. F., referred to................. 12
- Woodbridge, D. E., referred to.......99, 101
- Zapffe, Carl, referred to..............95, 102, 104, 110, 111, 112, 123, 124, 154

UNIVERSITY OF MICHIGAN
3 9015 00830 6766

OUN
JAN 30 1933
UNIV. OF MICH.
LIBRARY

6 charts
in pocket